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# Nuclear Power

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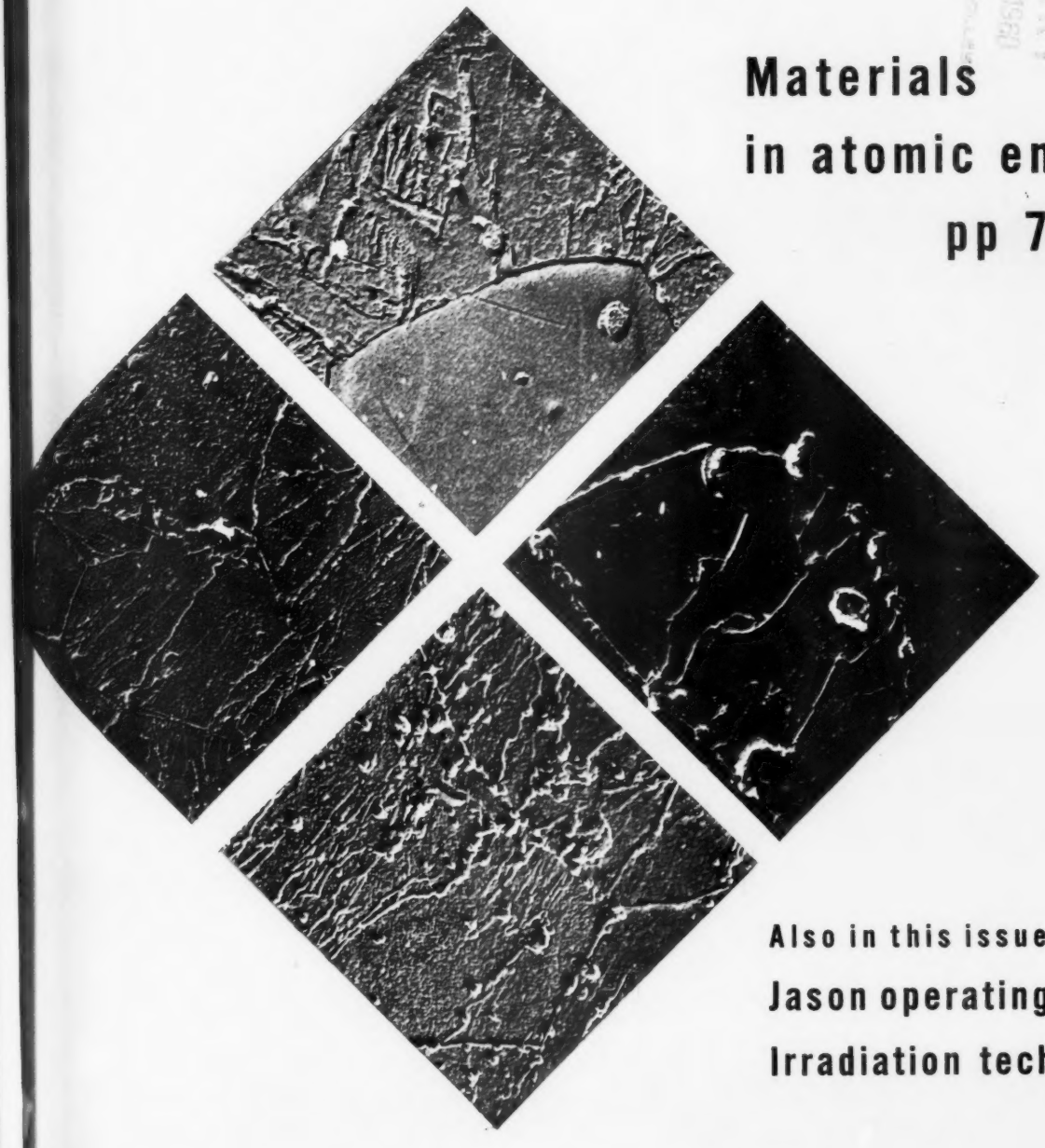

## Materials in atomic energy

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Jason operating experience

Irradiation techniques

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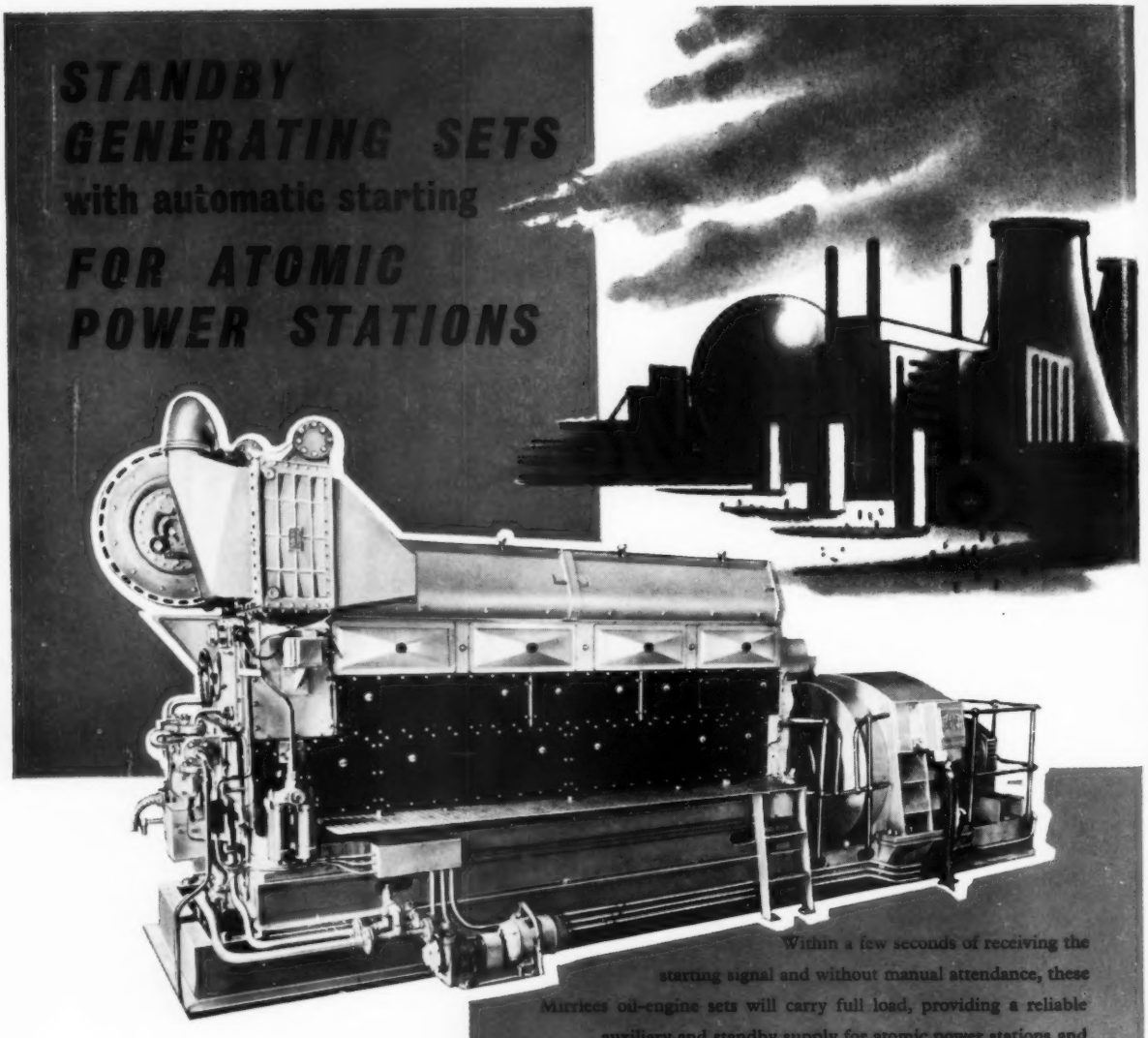

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# Nuclear Power

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VOL 5 NO 56 DECEMBER 1960



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*LOOKING FOR A JOB? SEE PAGE 150 AND ONWARDS*



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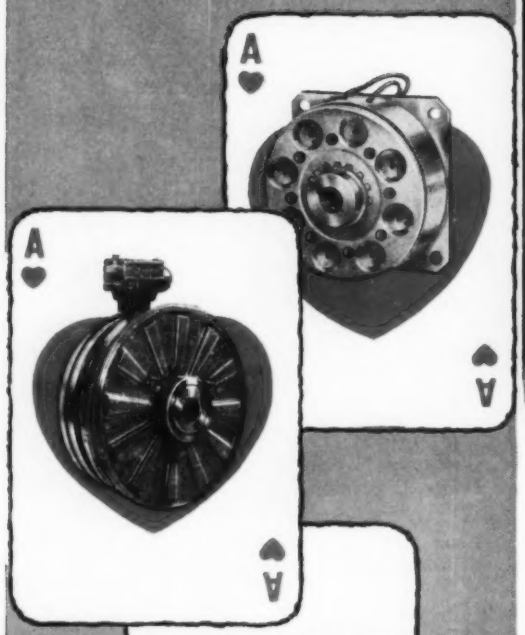

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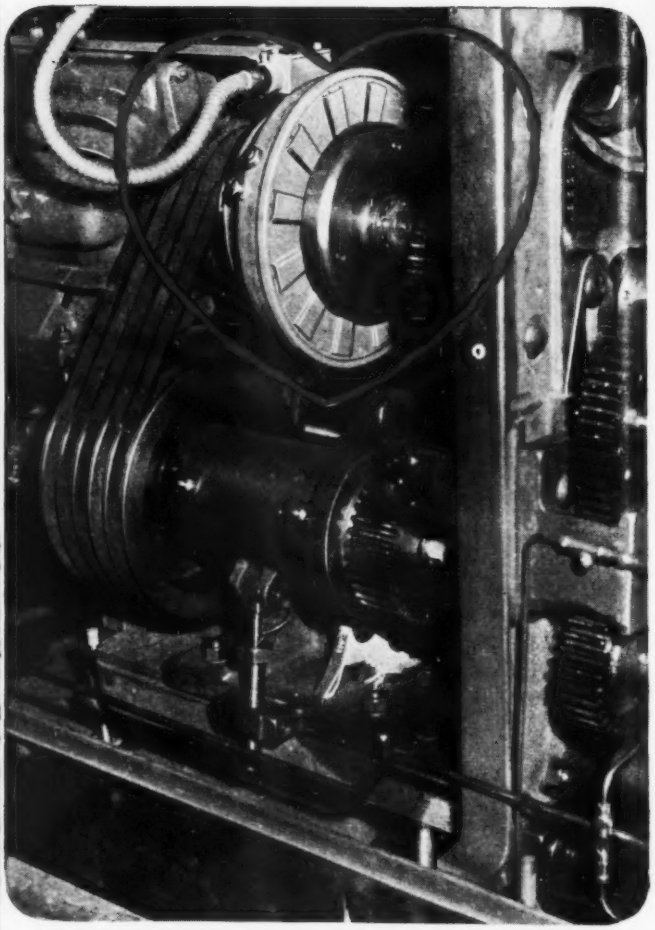

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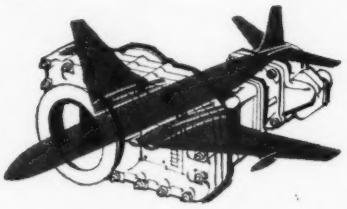

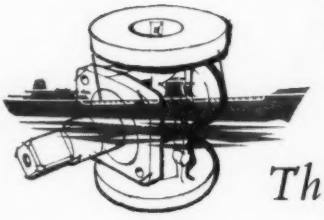

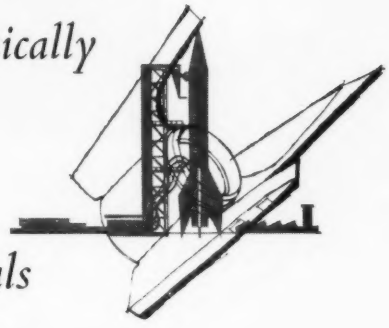

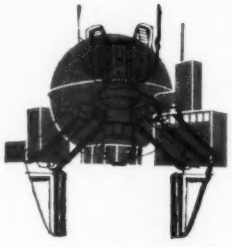

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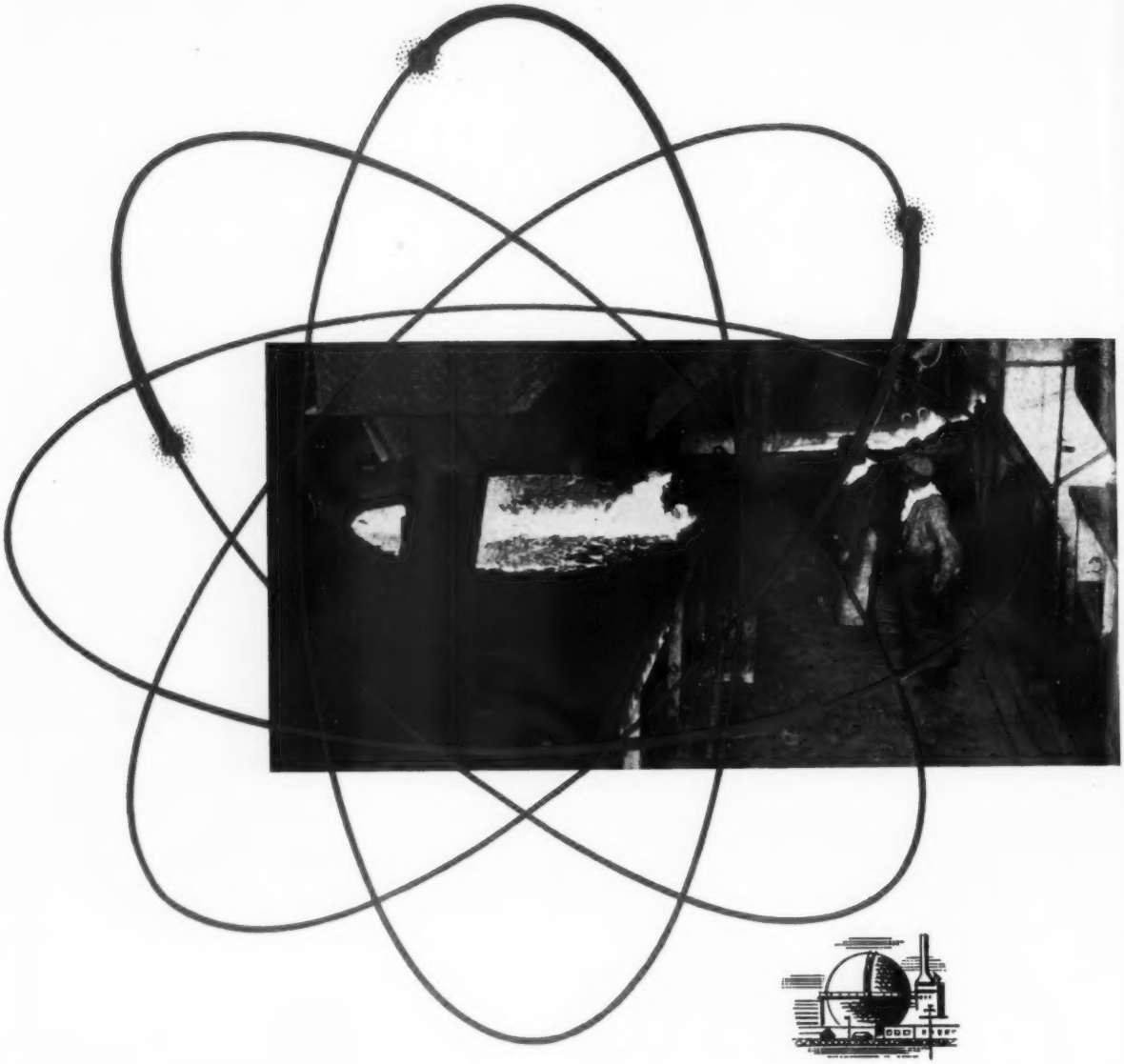

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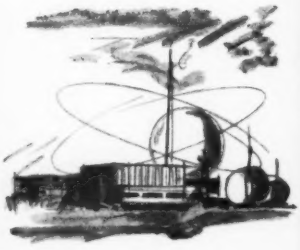

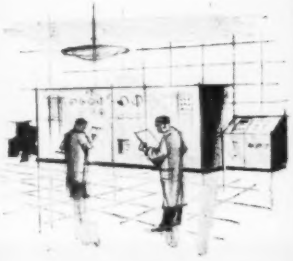

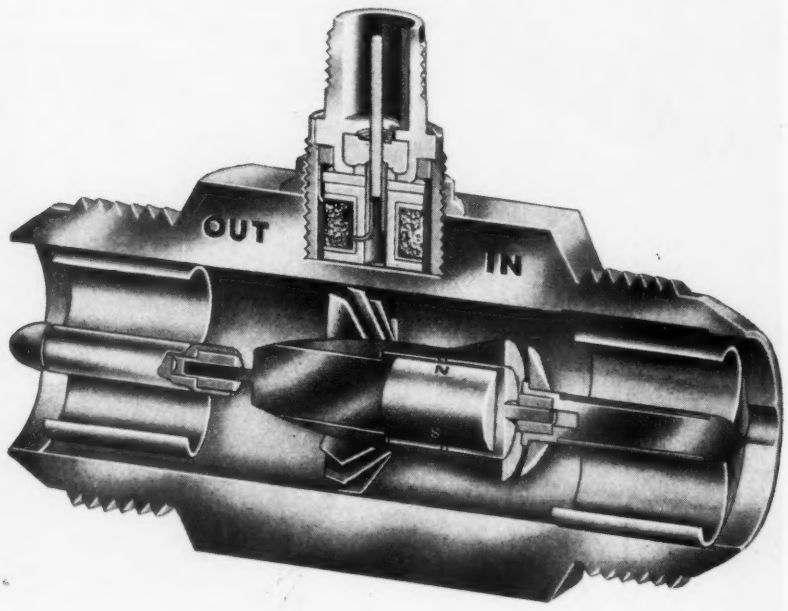


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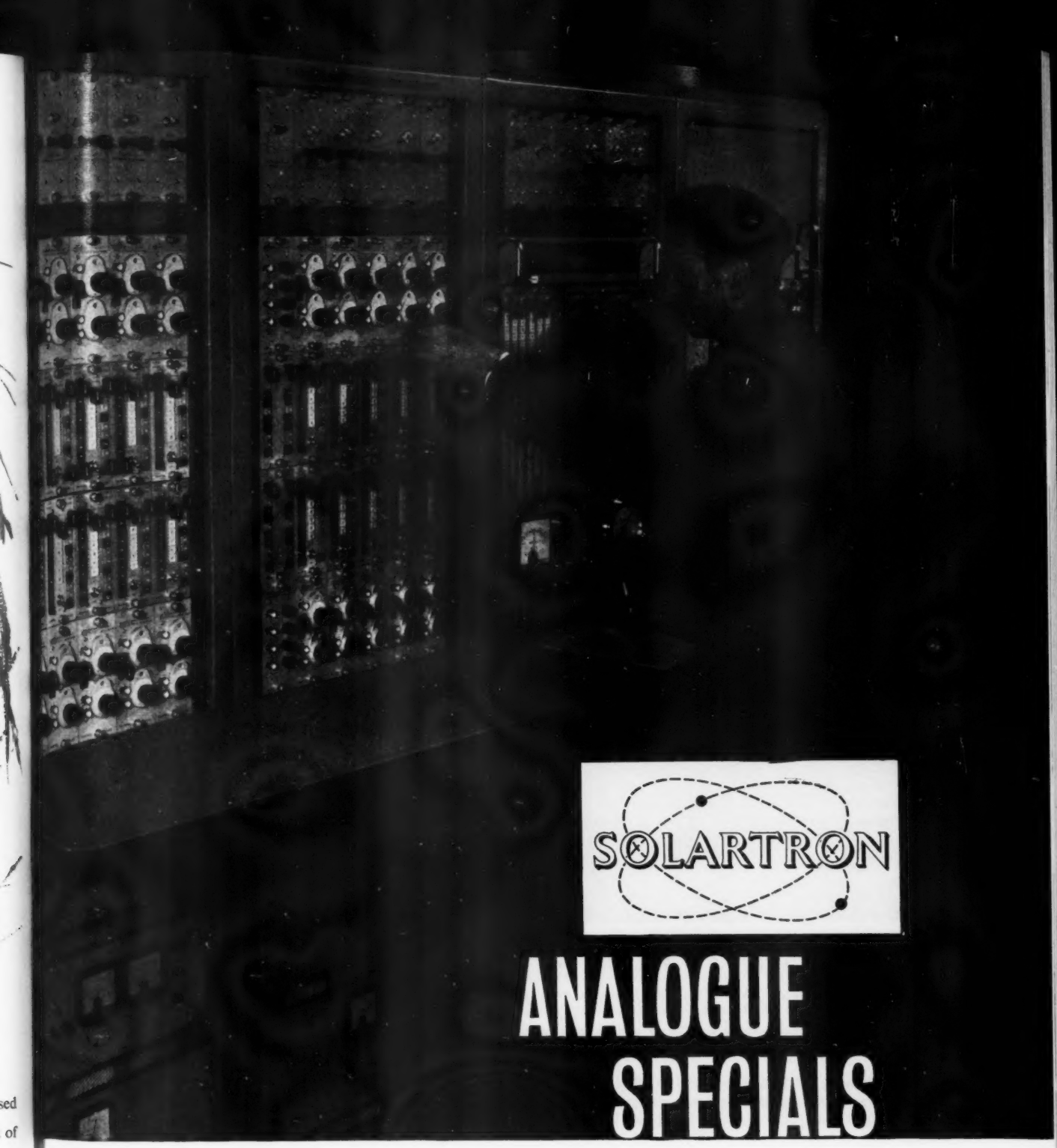

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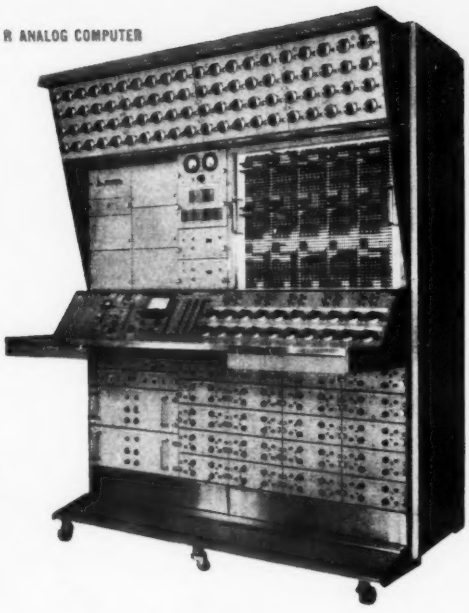

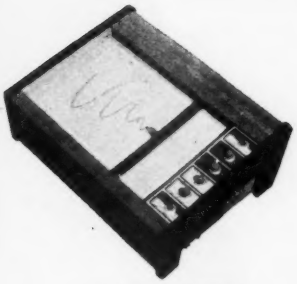

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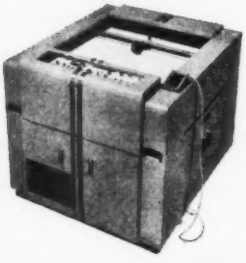

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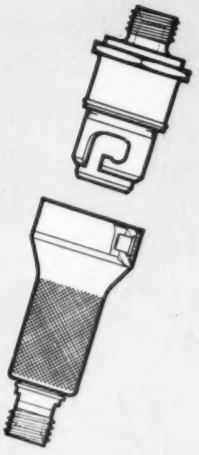


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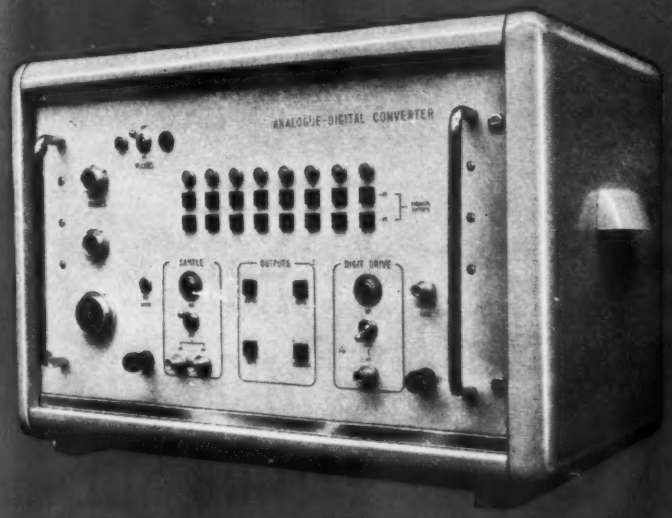


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Employment in scintillation counting and gamma spectroscopy are but two of a very broad range of applications in which these tubes are used.

## There is so much to be said . . .

about the 56AVP and the other twelve tubes in this range that you can gather all the necessary information only by studying the Mullard data sheets which will gladly be sent on request. Write now for these and for any further details concerning the Mullard photomultipliers and their applications. Here are brief details of the complete range

**51UVP** Eleven stage tube with 32 mm diameter photocathode and quartz end window to give sensitivity to ultra-violet.

**52AVP** Ten stage tube of 25 mm outside diameter and with 20 mm diameter photocathode.

**53AVP** Eleven stage tube with 44 mm diameter photocathode for use in gamma spectroscopy.

**53UVP** As 53AVP but with quartz end window to give sensitivity to ultra-violet.

**54AVP** Eleven stage tube with 111 mm diameter photocathode for flying spot scanners.

**56AVP** Fourteen stage tube with focused dynode structure giving rise time and transit time spreads of $2 \times 10^{-9}$ s. 42 mm diameter photocathode.

**56UVP** As 56AVP but with quartz end window.

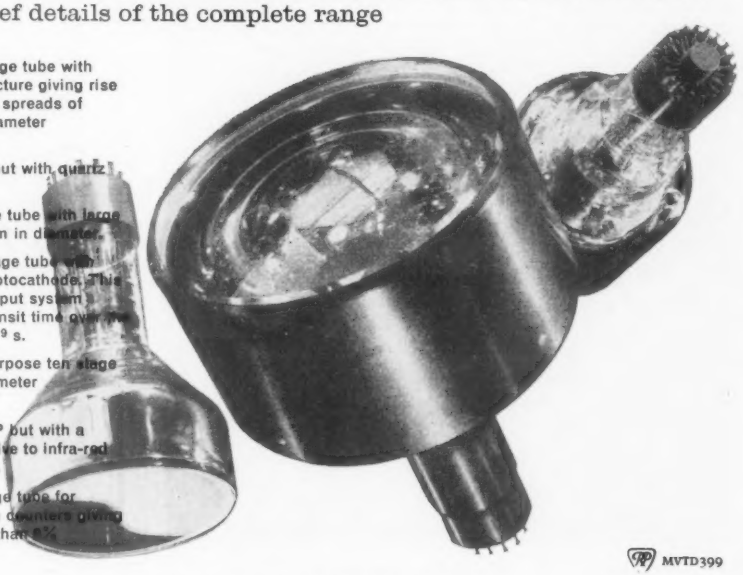
**57AVP** Eleven stage tube with large photocathode 200 mm in diameter.

**58AVP** Fourteen stage tube with 110 mm diameter photocathode. This tube has a tetrode input system giving spreads in transit time over the photocathode of $10^{-9}$ s.

**150AVP** General purpose ten stage tube with 32 mm diameter photocathode.

**150CVP** As 150AVP but with a photocathode sensitive to infra-red radiation up to 1.2 μ.

**153AVP** Eleven stage tube for use with scintillation counters giving a resolution of less than 8% with $Cs^{137}$.



MVTD399

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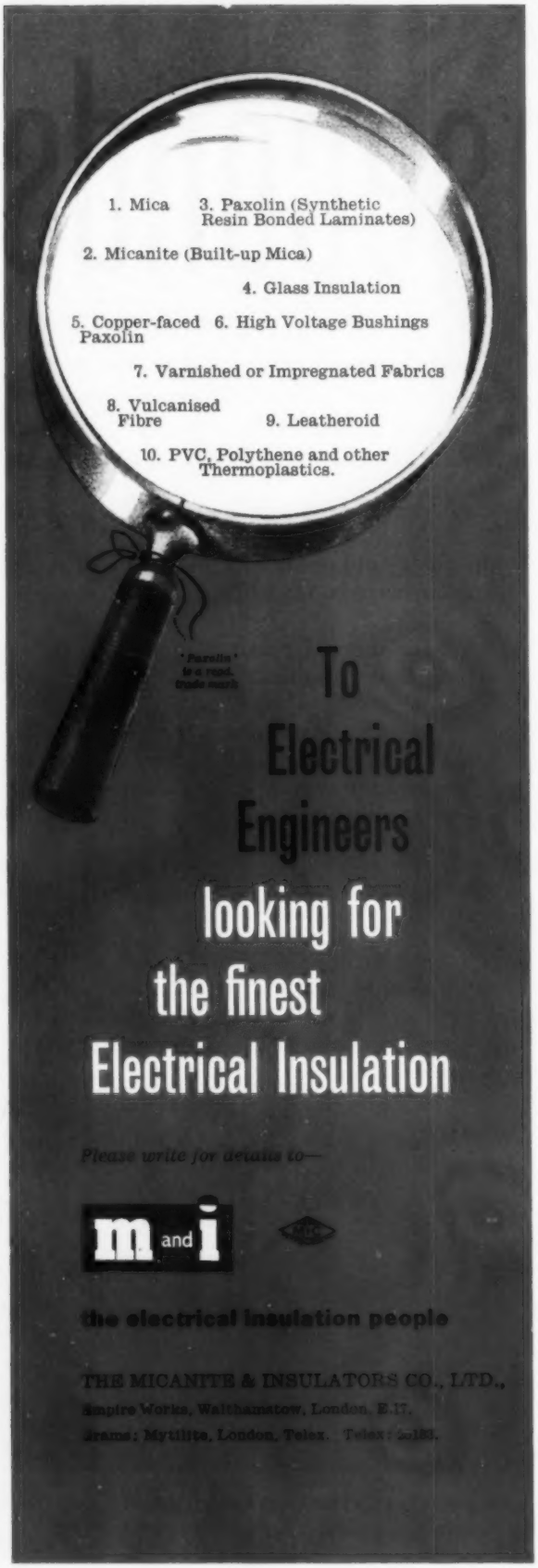
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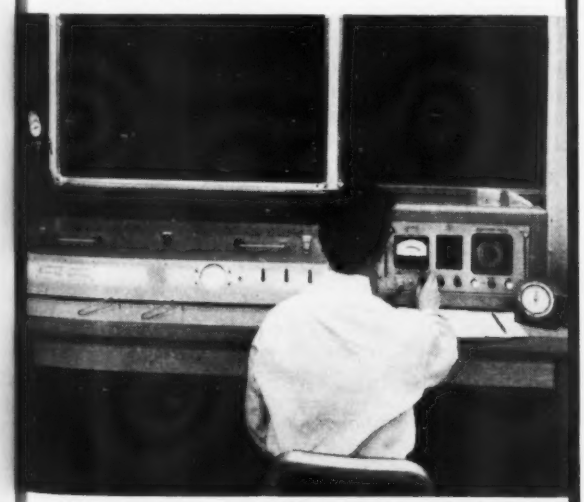

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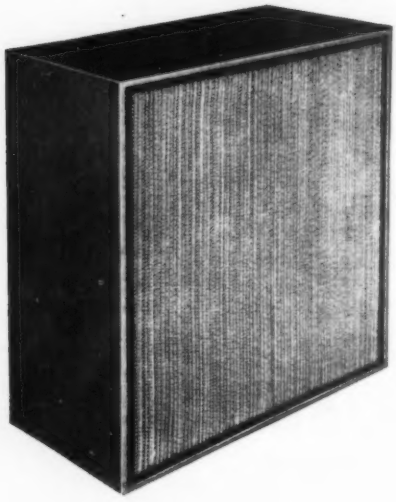
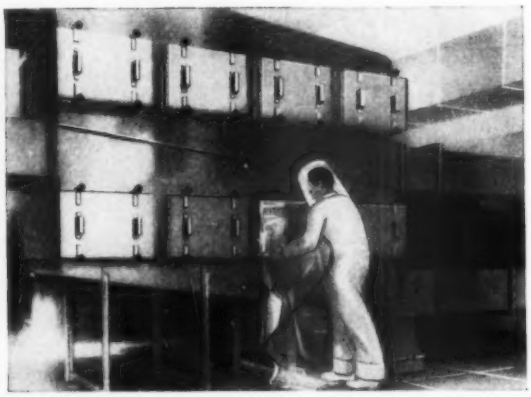
# This Vokes 'Absolute' filter is the nucleus of



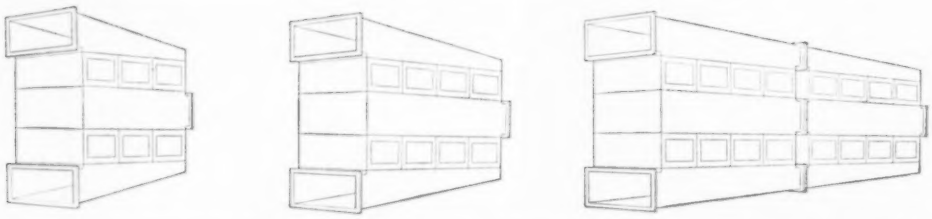
Originally developed for atomic energy work, Vokes 'Absolute' filters have also proved invaluable in biological, pharmaceutical and photographic applications — in fact wherever submicronic particles of dust and dirt can harm expensive equipment and processes. The special filter medium consisting of extremely fine asbestos fibres suspended in a grass-based paper gives a remarkable efficiency of 99.95% against particles in the 0.1 to 0.5 micron range — a figure guaranteed by subjecting every 'Absolute' filter to the methylene blue dust cloud test immediately before despatch. (B.S.S. 2831.)

Other 'Absolute' filters using an all-glass paper filter medium have *guaranteed* efficiencies as high as 99.99% — only 0.01% penetration against a methylene blue dust cloud. For further details please ask for publication HJ.

# this Vokes nuclear filtration plant — the Unipak



For the housing of 'Absolute' panels Vokes have designed the UNIPAK, an inexpensive, compact and adaptable structure consisting primarily of a sealing frame housed within an outer metal container. Complete inlet and outlet headers are provided, tailor-made to fit between the ventilation ducting and designed to the duct air velocity specified by the customer. Each 'Absolute' filter is isolated from the next and is easily and quickly fitted or removed by a patented sealing mechanism which, in addition to securing correct alignment of the filter, will not permit the access door to be replaced until it is sealed in position.



*Standardized components make possible the simple construction of multiple banks to handle a wide range of air volumes. The alternative layouts available — a few of which are shown in these sketches — make the UNIPAK suitable for most requirements. Our technical engineers are always at hand, however, to advise on special installations.*

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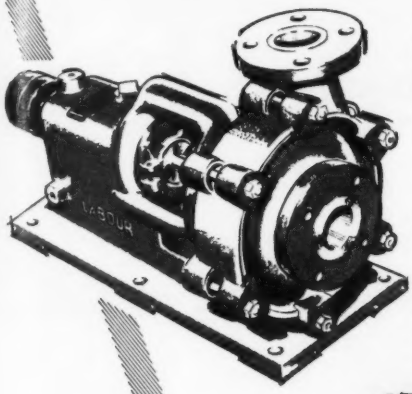

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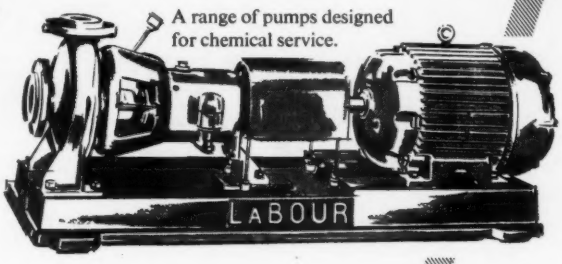
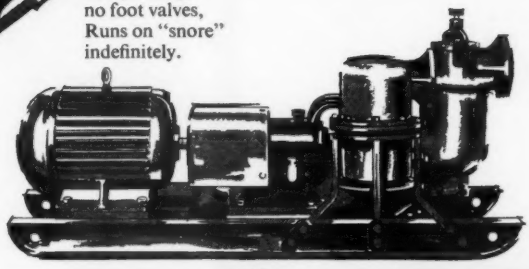



Specifically developed for mines. Operates in confined spaces. Self-priming, no foot valves, Runs on "snore" indefinitely.



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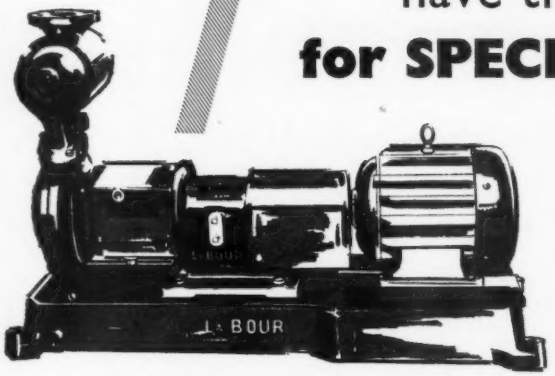
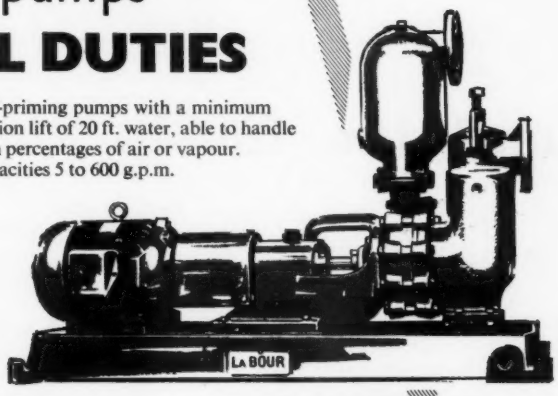



Self-priming pumps with a minimum suction lift of 20 ft. water, able to handle high percentages of air or vapour. Capacities 5 to 600 g.p.m.

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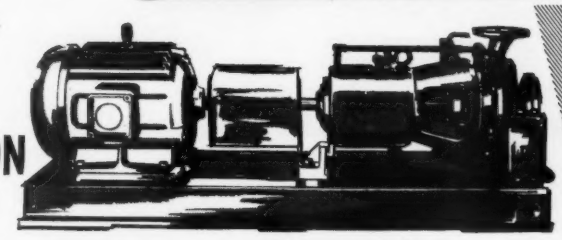

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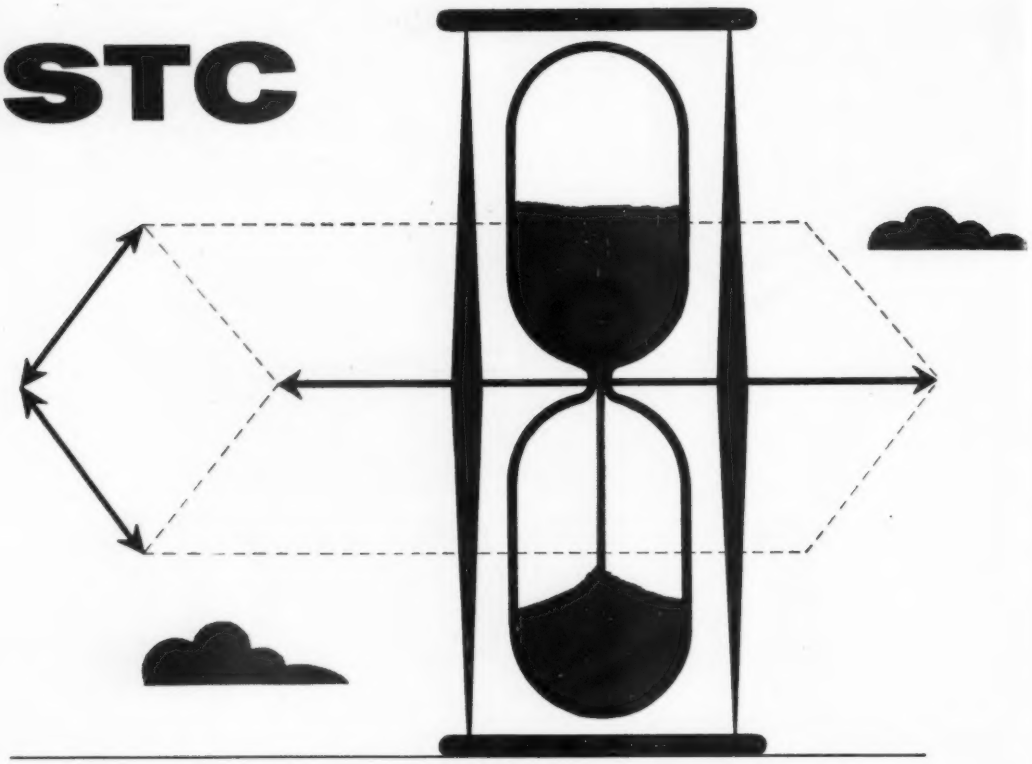

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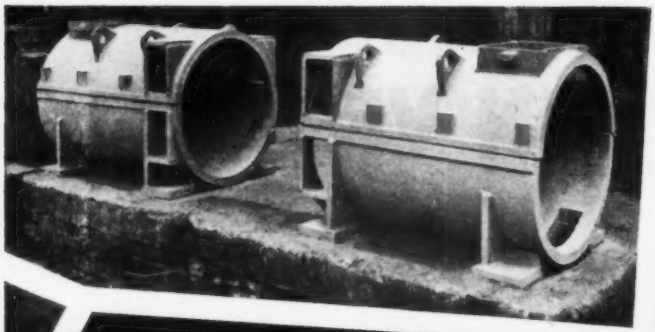

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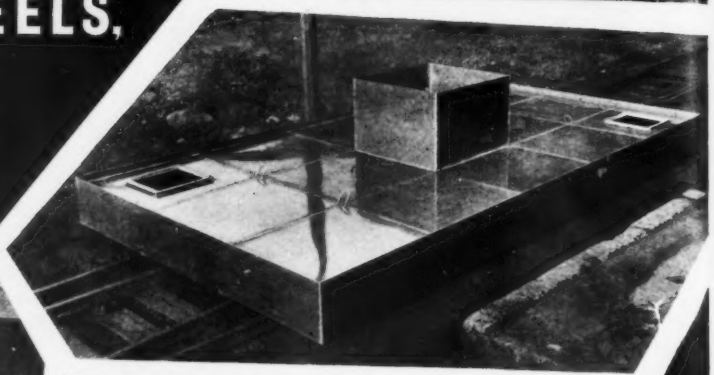

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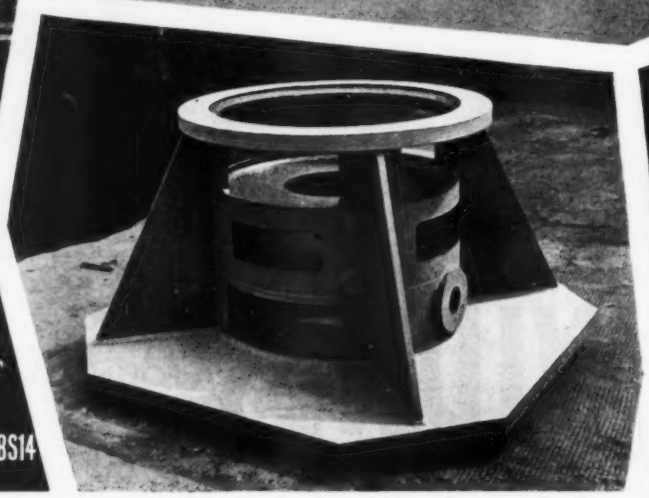

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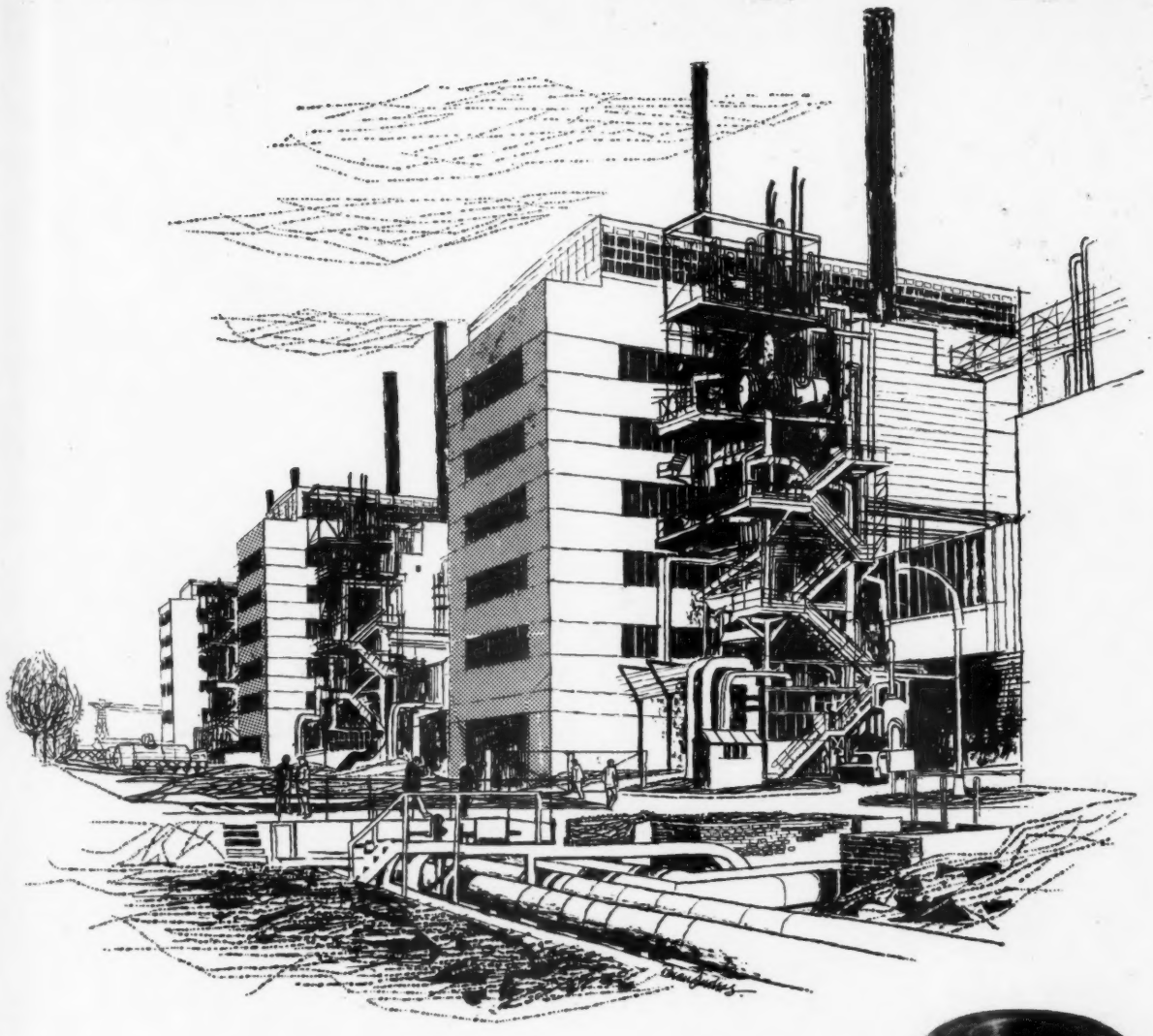

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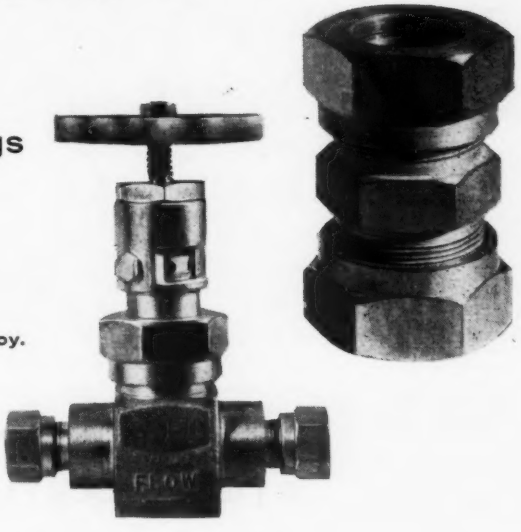


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# managing director

...They always say that the leaves grow greener in the other fellow's garden—but I doubt it.

"Seems to me that being a Managing Director would have its drawbacks. Having to entertain customers when I fancied a yarn with the boys and only seeing a leek when it was dished up in a tureen would drive me fair barmy inside a month.

"Mind you—don't get me wrong. If somebody offered me the job I'd have a shot at it, but deep down I feel that the boss's chair calls for a little more than most of us can give. In the 40 years I've worked for the AW Group I've learned to handle men and make a quick decision. I can talk about steel until the cows come home and I know a few tricks that the professors don't teach . . . but as for being a Managing Director . . . I reckon I'll stick to my own garden after all."

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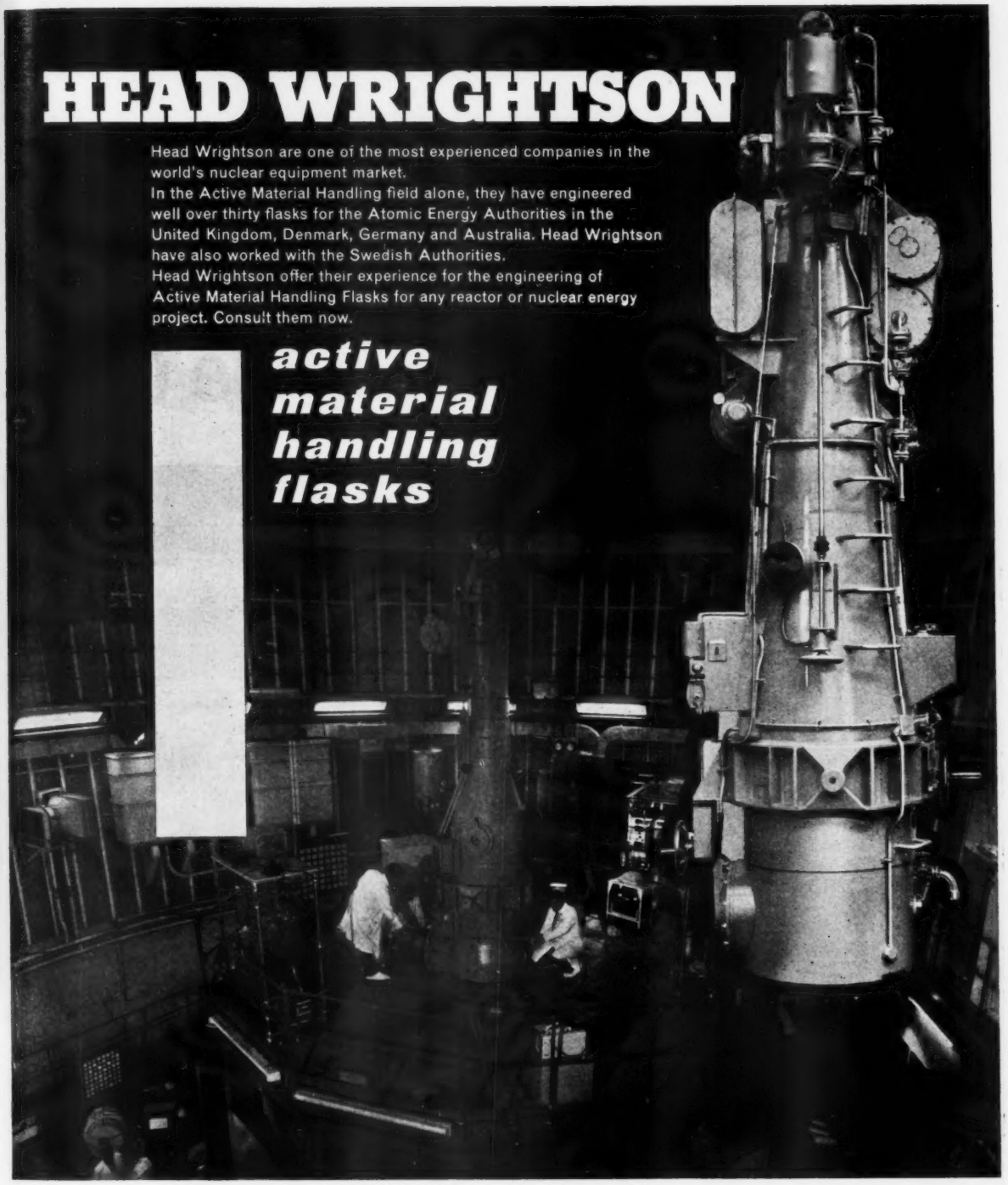

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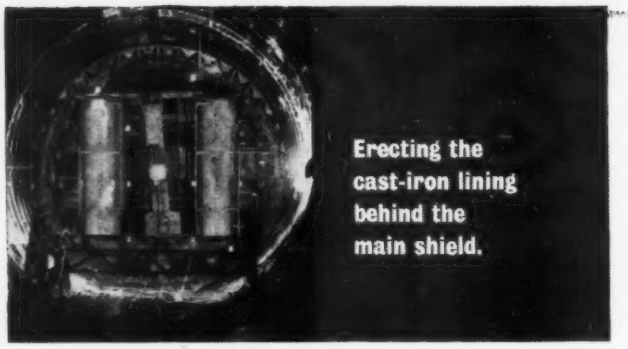
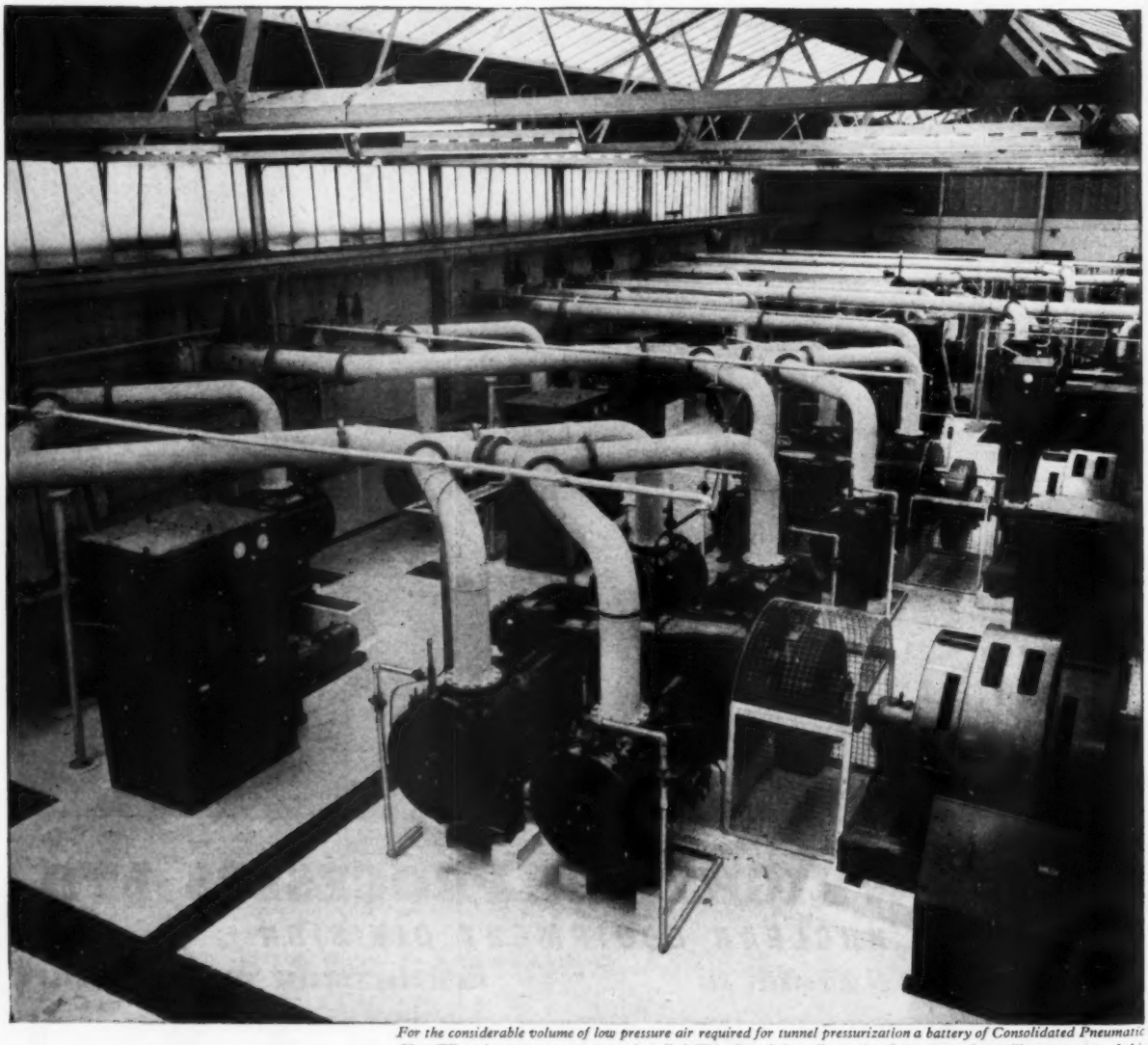
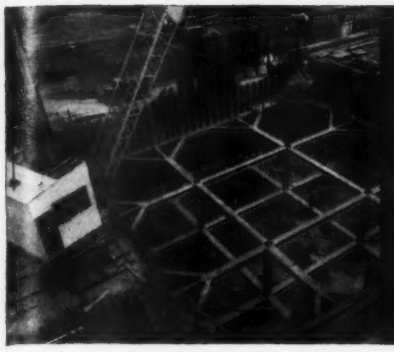


Erecting the cast-iron lining behind the main shield.

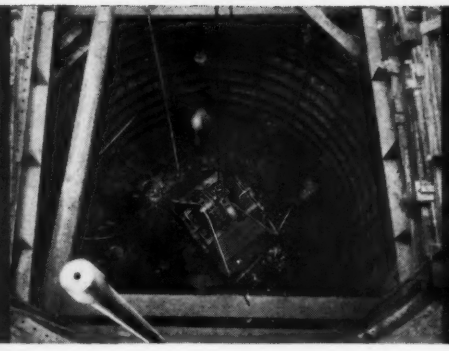
# Charles Brand drive the Clyde



*For the considerable volume of low pressure air required for tunnel pressurization a battery of Consolidated Pneumatic Class FE stationary compressors was installed. This view of the well-appointed compressor house illustrates part of this installation of slow-speed, double-acting, balanced-opposed machines. Class T compressors from the Consolidated Pneumatic range were installed to provide air at working pressure for pneumatic tool operation.*



A view of the coffer dam for the portal entrance.



Excavating one of the 18-ft. diameter main shafts.

# Tunnel with CP equipment

Leading Civil Engineering Contractors, Charles Brand & Son Ltd., one of the most experienced low pressure tunnelling specialists in the country, are now engaged on a contract which is probably the largest project of its type yet undertaken — the new Clyde Tunnels being constructed for the City of Glasgow Corporation. In this field of work, perhaps more than in any other, the quality and performance of plant and equipment is of paramount importance. Charles Brand have chosen Consolidated Pneumatic equipment for the major part of the compressed air installations and the rock drilling operations. The good progress revealed in these pictures pays tribute to the contractors, and reflects in turn the efficiency of the CP equipment employed.

*Consulting Engineers: Sir William Halcrow and Partners,* MM.I.C.E.

*Excavation work at the face of the pilot tunnel.*

**Consolidated Pneumatic**

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*Affiliated and Subsidiary Companies throughout the world.*

CP/21S

AIRMEC

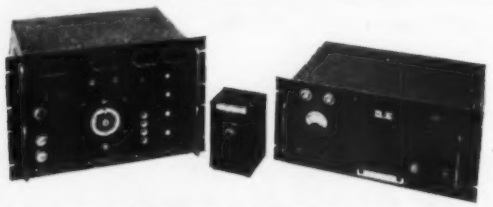
# MONITORS

## FOR BENCH OR FIELD USE

### TYPE 255

- **PORTABLE**
  Transistorised, battery operated, weighs only 16 lbs with batteries
- **ACCURATE**
  Laboratory accuracy under field conditions. Accuracy of measurement generally better than ± 2·5%, which is not affected by falling battery voltage
- **VERSATILE**
  Wide range of probes and accessories available, including Alpha, Beta Gamma, End Window and Liquid sample probes, a Sample Holder and a Lead Castle. A stout leather case is available for carrying the probes.

*WRITE FOR DESCRIPTIVE LEAFLET No. 177B*



**GENERAL PURPOSE COUNTER TYPE 1339A**

### TYPE 1021B

- **SAFEGUARDS** against contamination
- **TRACES** radio-active material in chemical analytic processes
- **MEASURES** contamination of any resulting effluent

Designed in conjunction with A.E.R.E. Harwell, this instrument is probably the most widely used general purpose monitor in the world. It has been PROVED by years of user experience to be the most accurate and reliable equipment of its type. The Radiation Monitor consists of a mains operated Indicator Unit together with a Beta Gamma or Alpha Probe Unit. Indication is provided visually by means of a meter which is calibrated in counts per second, and audibly by means of a loudspeaker. A socket on the front panel is also provided to enable the output to be fed to a scaling unit.

*WRITE FOR DESCRIPTIVE LEAFLET No. 26D*

## AND A SCALER FOR THE LABORATORY

- Provides comprehensive scaling facilities for all types of Geiger Scintillation Counters
- Incorporates stabilised E.H.T. Supplies
- Fitted with automatic timing control
- Designed and developed in conjunction with U.K.A.E.R.E.

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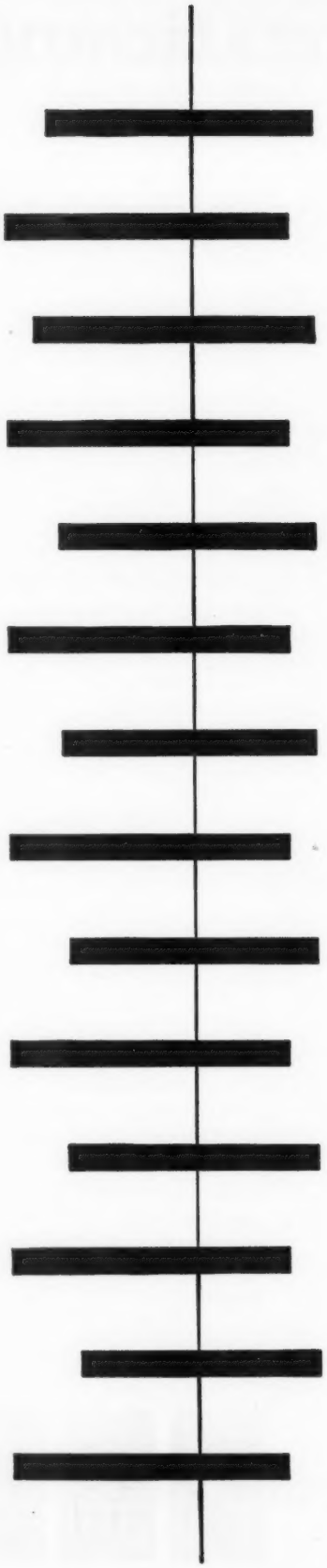
Airmec

**Instruments for the Nucleonic Age**

AIRMEC LIMITED · HIGH WYCOMBE · BUCKS · Tel: High Wycombe 2501-7



# hector

a new zero-energy nuclear reactor

for the United Kingdom Atomic Energy

Authority's establishment at

## WINFRITH HEATH

Design and construction by

## FAIREY ENGINEERING LTD

**Heston · Middlesex and Stockport · Cheshire**

*A subsidiary of The Fairey Company Limited*



Circle **No 30** on reply card for further details

# static and

**High output**

**Low temperature drift**

**All-round accuracy**

**Single-ended pressure transducer type 1029**

| | |
|---|---|
| *Sensitivity* | 60 mv/v |
| *Non-linearity and hysteresis* | 1% |
| *Zero drift* | better than 0.01% /° C |
| *Thermal co-efficient of sensitivity* | .02% /° C up to 200 p.s.i.<br>.05% /° C above 200 p.s.i. |

**Differential pressure transducer type 1028**

| | |
|---|---|
| *Sensitivity* | 30 mv/v |
| *Non-linearity and hysteresis* | 1% |
| *Zero drift* | better than 0.01% /° C |
| *Thermal co-efficient of sensitivity* | .02% /° C up to 200 p.s.i.<br>.05% /° C above 200 p.s.i. |

Rugged N E P single-ended and differential pressure transducers accurately measure static and dynamic pressures at temperatures up to 200°C.

Gauge or differential fluid pressure ranges from 0-5 p.s.i. to 0-5000 p.s.i.

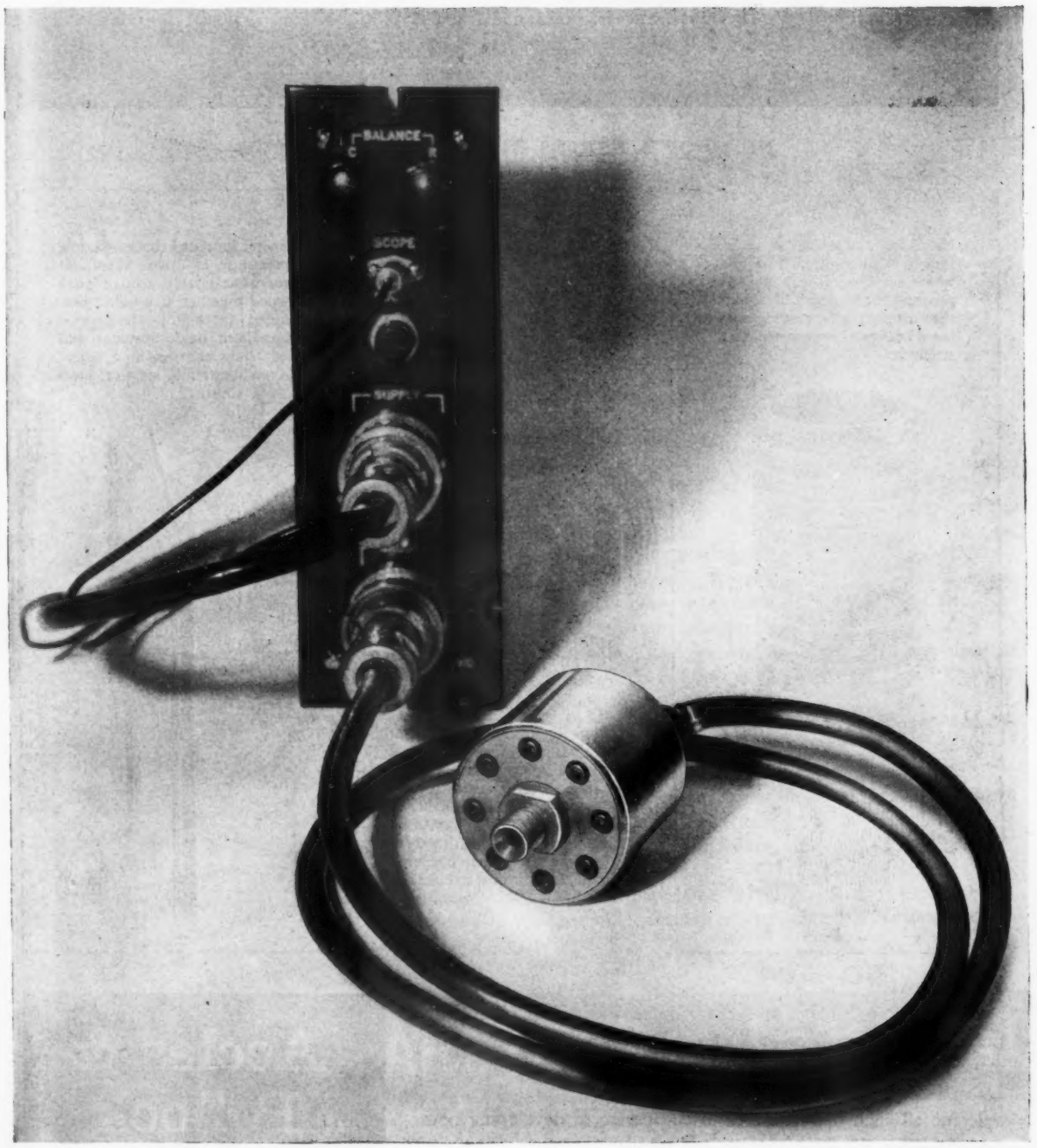
N E P inductive type transducers are suitable for dynamic pressure analysis with almost any fluids.

These transducers are designed to be used in conjunction with the N E P oscillator-demodulator unit. This provides an output proportional to the fluid pressure which can be used for operating controllers or can be recorded on the N E P process-free Direct Writing Galvanometer Recorder.

*Suppliers of recording instruments and systems to the aircraft and G.W. industries, Government establishments, Admiralty, etc., A.I.D. approved*

N E P

# dynamic pressures at 200°C




## New Electronic Products Ltd

MAKERS OF SCIENTIFIC MEDICAL AND INDUSTRIAL INSTRUMENTS

Head office and works: 360 Kennington Road London SE11 RELiance 5161



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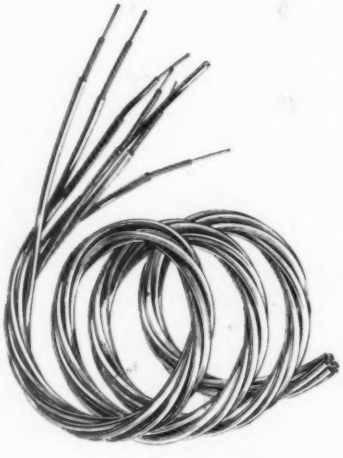
Some recent developments in manufacturing techniques and special applications of tubes in a variety of metals . . .

NO. 10 OF A SERIES BY ACCLES & POLLOCK

Helically gilled extended surface tubing in zirconium. The gills, which are integral with the base tube and disposed helically around the tube periphery, provide maximum heat transfer properties and strength.



A flexible duct for instrument control which consists of a number of small diameter seamless stainless tubes interwoven to form a single cable and then helically coiled to obtain flexibility. One of the tubes is left open to carry gas and the rest contain insulated wire for the electrical circuits.

Mineral insulated thermo-couple consisting of two dissimilar thermo-electric conductors welded together at a point, embedded in highly compressed magnesium oxide insulant and completely encased in a small, circular austenitic stainless steel tubular sheath.

Designers have a habit of asking for the impossible, but in a surprising number of cases Accles & Pollock produce an answer that enables the production people to translate the concept on the drawing-board into a physical, functional form. Accles & Pollock welcome all such opportunities to co-operate in developing new applications in the form of tubes and tubular sections.

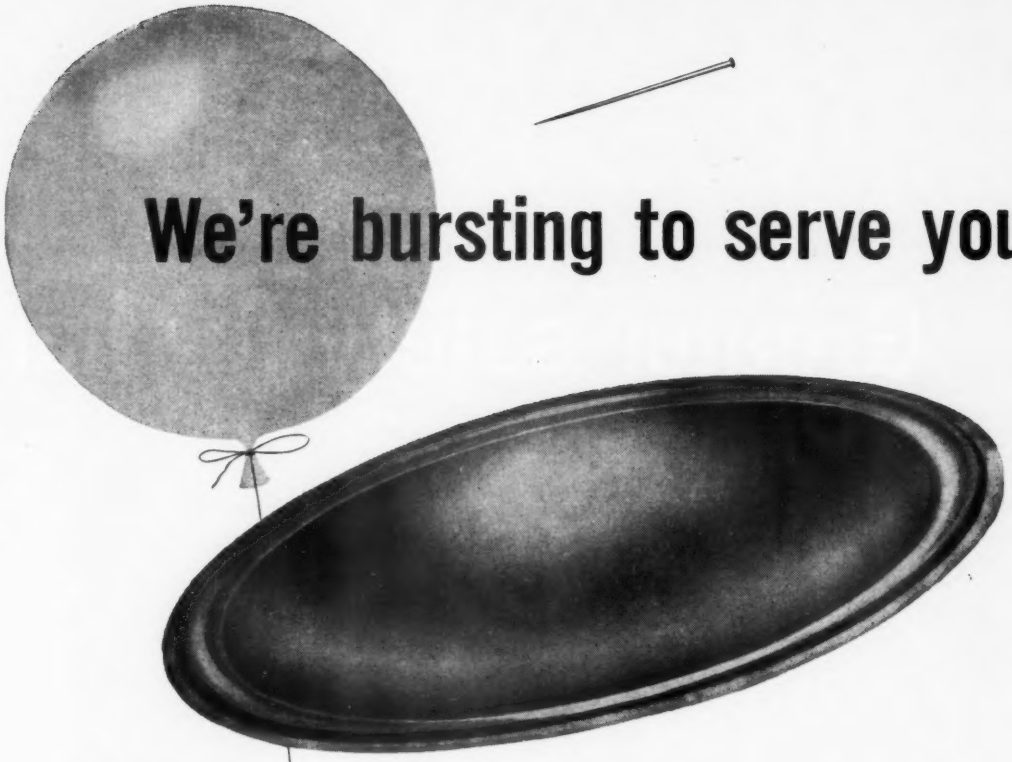
Accles & Pollock

*Technical Information Sheets discussing tubes and their applications are available on request.*

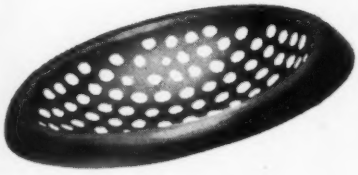
ACCLES & POLLOCK LIMITED · OLDBURY · BIRMINGHAM · A TI COMPANY

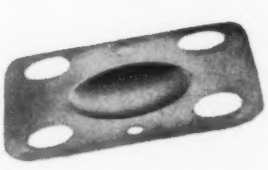
**Makers and manipulators of COLD DRAWN SEAMLESS and WELDED PRECISION TUBES in carbon and alloy steels, including stainless steel, and other metals.**

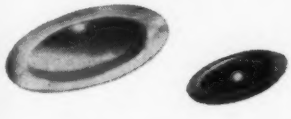
TS W/387



# We're bursting to serve you!







More and more engineers are specifying Marston Excelsior Bursting Discs to ensure the safe operation of pressurized vessels. With no working parts to foul or clog, Marston Excelsior Bursting Discs provide the surest protection for plant and operatives. Immediately the pre-determined pressure of a vessel is exceeded, the disc ruptures and allows release through the full bore of the orifice.

Marston Excelsior Bursting Discs and Carriers are manufactured in a range of sizes from 11/16 in. to 5 ft. diameter, to cover almost every bursting pressure. A wide variety of metals is available, including Aluminium, Copper, Silver, Lead, Nickel, Stainless Steel, Monel, Brass, Platinum and Palladium, and non-metallic materials such as Rubber/Canvas, Neoprene and "Klingerite".

Marston Excelsior have taken over the manufacture of Bursting Discs from the Billingham Division of I.C.I.—and with it a vast knowledge of these safety devices in actual use. Now, this detailed experience and the skill of Marstons combine to ensure perfect service under all operating conditions.

## MARSTONS make it safe!

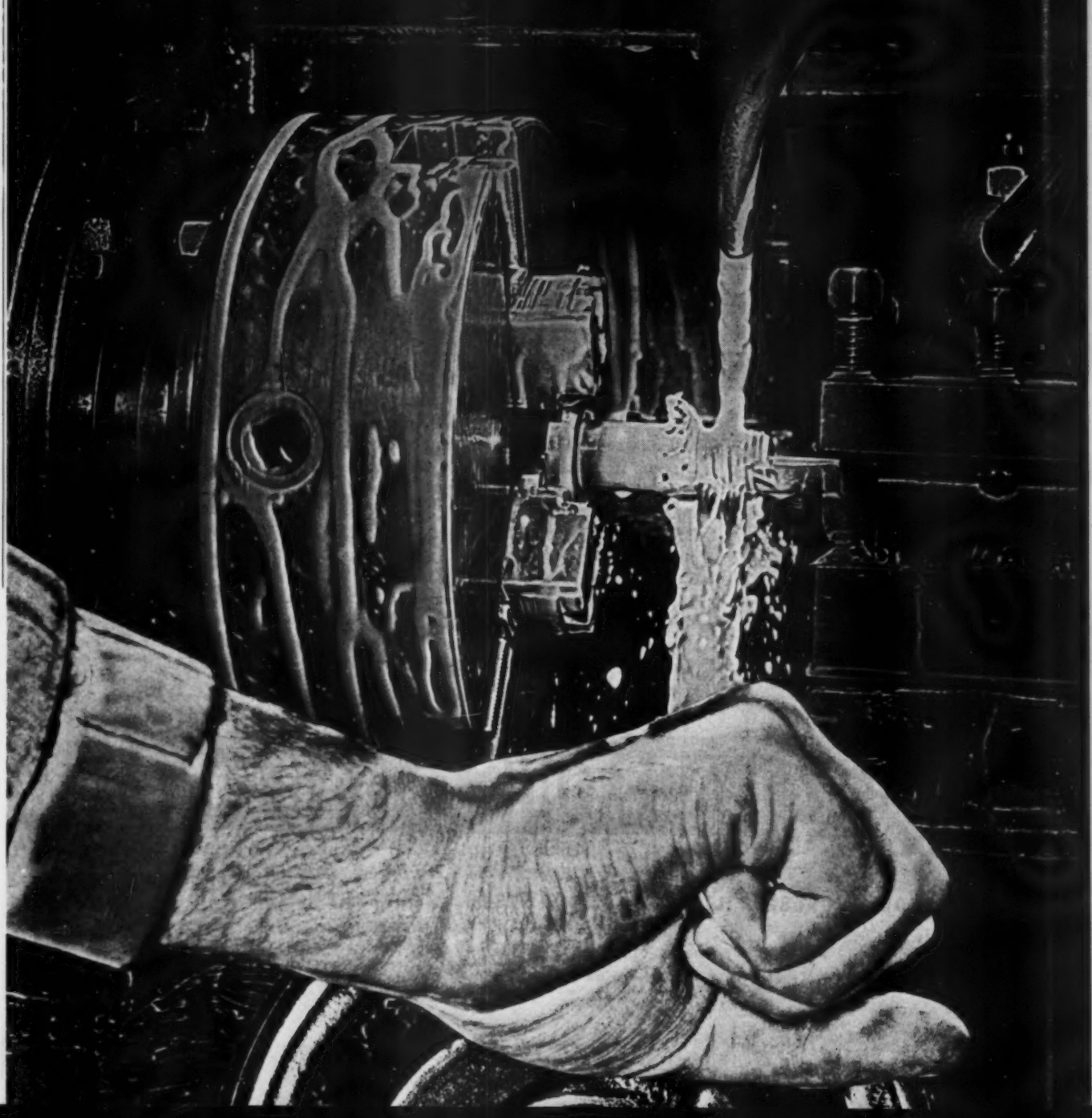
*For fullest details, write now to:*

**MARSTON EXCELSIOR LIMITED, FORDHOUSES, WOLVERHAMPTON**

*(A subsidiary company of Imperial Chemical Industries Ltd.)*

MAR203

# Greater safety for hands



# With new Shell Dromus Oils

Most modern soluble cutting oils contain phenolic compounds used as coupling agents between the oil and the emulsifier, for better blending and easier mixing. These phenolic compounds can cause skin irritation, especially where modern high-speed machines are used and the emulsion can concentrate, through the evaporation of water, above the safety level.

Shell research chemists have been working on this problem, which has been causing some concern to Management. After considerable research, Shell Dromus Oils have been reformulated and these new cutting oils now produce bland emulsions, which considerably reduce the risk of skin trouble to operators.

The real difficulty was to find a new coupling agent to replace the phenolic compounds, and Shell finally used what their chemists know as a higher fatty alcohol complex. This solved one problem, but presented another. The new coupling agent was volatile at the high temperatures normally used in blending processes. Further research found a solution to this problem by designing and installing new plant.

The new Dromus Oils are every bit as efficient as before and cost no more. They put Management in the welcome position of being able to minimise working hazards at no extra cost. And machine men need no longer be so worried about skin troubles.

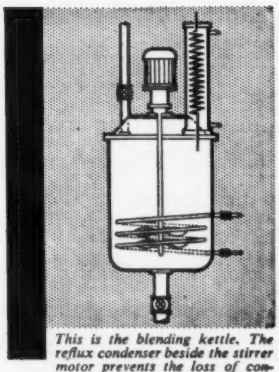
The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organization have any major lubricating problems, it pays to get in touch with your local supplier of Shell Industrial Lubricants.

## The Research Story

Shell chemists in the U.K., in Holland and in the U.S.A., prepared and examined hundreds of experimental soluble oils, and established that certain combinations of fatty alcohols could be used in place of phenolic compounds with no loss of efficiency. They set to work to discover the best combination and developed a higher fatty alcohol complex which fitted exactly. Then they realised that to blend this new coupling agent into soluble oils would require special plant and new blending techniques.

Exhaustive testing of blend stability, emulsion stability, anti-corrosion and machining properties led to selection of the most promising blends. A pilot plant was set up to produce batches of these for use in field trials.

This field testing and final development proceeded for two years whilst production plants were erected at points so chosen as to give the most economical and rapid delivery throughout the United Kingdom.



*This is the blending kettle. The reflux condenser beside the stirrer motor prevents the loss of constituents volatile at the blending temperature.*

**NEW SHELL DROMUS SOLUBLE CUTTING OILS**

another proof of Shell leadership in lubrication



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# 11 out of top 20

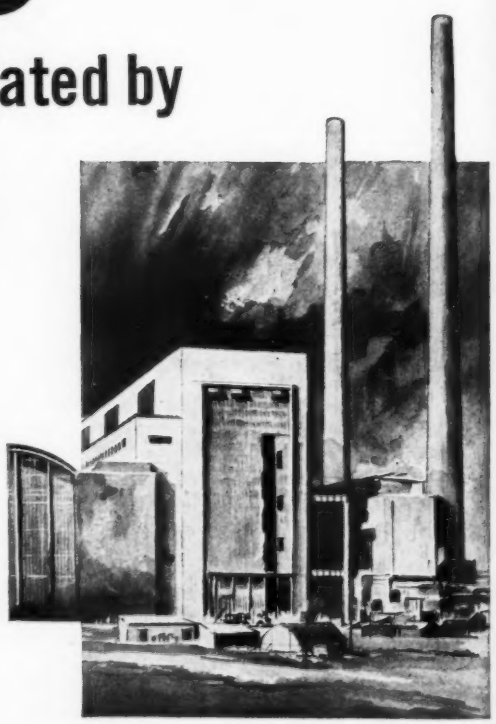
for thermal efficiency insulated by

# DARLINGTON

| | |
|---|---|
| Blyth 'A' | 33.88% |
| Agecroft 'C' | 32.63% |
| Castle Donington | 32.52% |
| Drakelow 'B' | 32.14% |
| Willington 'A' | 31.96% |
| Drakelow 'A' | 30.81% |
| Rogerstone | 30.44% |
| South Denes | 30.11% |
| Stourport 'B' (HP) | 30.04% |
| Littlebrook 'B' | 29.76% |
| Stella North | 29.36% |

Here's further conclusive evidence that The Darlington Insulation Co. Ltd. is the leading company of its kind in Britain! Of the twenty power stations that top the list for thermal efficiency in 1959 in the Central Electricity Generating Board analysis, eleven – including the first three – were insulated by Darlington. Eleven good reasons for choosing Darlington for all industrial insulation problems!

The same comprehensive technical advisory service that achieved these results is available to *you*. Address any thermal insulation problem you may have to



## The Darlington Insulation Co. Limited

38 Great North Road, Newcastle upon Tyne, 2 *A Member of The Darlington Group of Companies*

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Regd Trade Mark
ALUMINOUS CEMENT

For

# *HEAT-RESISTANT CONCRETE

## WITH SPECIAL PROPERTIES FOR SPECIAL PROBLEMS

Exceptional cold strength at 24 hours and permanent residual strength for structural purposes at elevated temperatures.

Great thermal shock resistance.
Volume stability at temperature.
Low thermal conductivity.
Highly resistant to chemical attack.

***Shielding action at elevated temperatures due to high proportion of combined water.***

(*Temperature limit up to 1350°C, dependent on type of heat-resistant aggregate employed !)

## Our Technical Dept. is entirely at your disposal for further specific information

CIMENT FONDU
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ALUMINOUS CEMENT

**FOR SPEED—STRENGTH**

**RESISTANCE**

**REFRACTORINESS**

Manufactured by
**LAFARGE ALUMINOUS CEMENT COMPANY LTD**
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For operating temperatures up to 1800°C, or when a refractory resistant to reducing conditions is required, use Super-Duty Refractory Concretes made with SECAR 250, a pure white calcium-aluminate cement, free from iron oxides. Write for details.

AP122

# HIGH EFFICIENCY PIPE INSULATION DATA

**MINUS 400° F**

**to PLUS 1500° F**

# STILAG

**PREFORMED MINERAL WOOL PIPE INSULATING SECTIONS**

Technical Data Leaflet No. 7 contains useful tables of recommended thicknesses of STILAG insulation for various pipe sizes over a range of temperatures together with relevant 'K' values, heat losses and surface temperatures. Please send the coupon for your copy.

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*Please send me Technical Data Leaflet No. 7.*

NAME .....

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*Just attach this coupon to your letterhead.* *Nuclear Power*

STILLITE

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**STILLITE PRODUCTS LTD.**

**15 Whitehall, London, S.W.1. Tel: WHitehall 0922/7**

*231 St. Vincent Street, Glasgow, C.2. Tel: Central 4292*

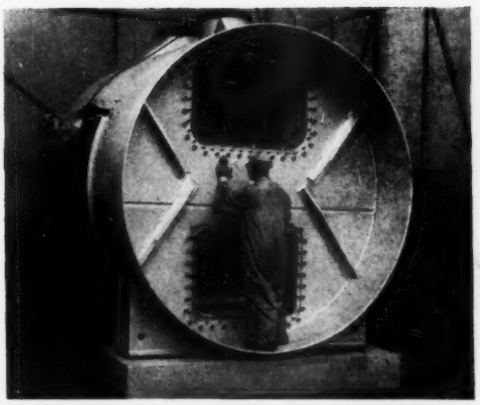
# The name of Fairey...

To most of us the name of Fairey has always been linked with famous aircraft, not the least of which was the Delta 2 in which the World Absolute Speed Record was raised to 1132 m.p.h. But in recent years the interests of the Company have been spread widely throughout the field of industry.

For example, just outside Stockport, at Heaton Chapel, Fairey Engineering Ltd. operates a large plant for the fabrication and welding of aluminium and steel structures. The engineers here have developed special techniques based on the extremely high standards of quality inspection demanded in aircraft production, and for many years the plant has been engaged in making equipment for the United Kingdom Atomic Energy Authority, where standards are equally high. The company is expanding its training school for welders and building a new block of Metallurgy and Welding Engineering Development Laboratories.

Fairey metallurgists and quality inspection engineers attach special importance to X-ray and gamma-ray inspection of castings and welds, and the radiographs are carefully filed to provide proof of sound casting and welding techniques. The greater percentage of products leaving the Heaton Chapel works are radiographed.

And for this vital evidence of sound workmanship Fairey Engineering relies on Kodak "Industrex" X-ray Films—the last vital check in a chain of quality control techniques.



*A 4½-ton aluminium fabrication made at Heaton Chapel for the U.K.A.E.A.*

*A core skirt for a nuclear reactor.*

*100% weld radiography is carried out on all vital assemblies at Heaton Chapel. Kodak "Industrex" X-ray films are used for this quality control.*

## Kodak
## Industrial X-ray Films

**... first choice of inspection engineers everywhere**

*If you are not yet using radiography to check the quality of welds or castings send for a free copy of a 32-pp booklet "Can Industrial Radiography help you?"*

Kodak Limited, Industrial Sales Division, Kodak House, Kingsway, London, W.C.2.



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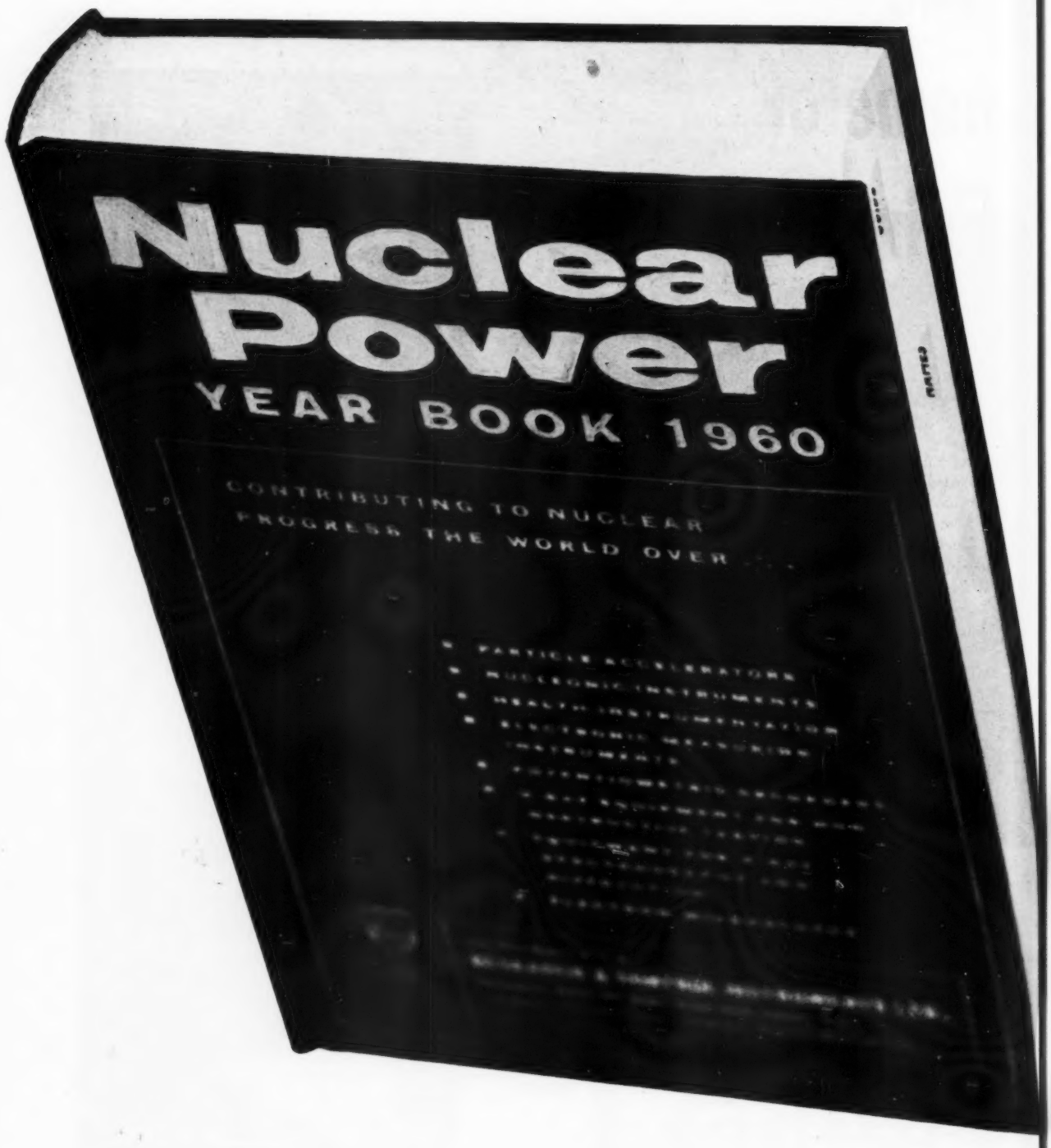
Nuclear
Power
YEAR BOOK 1960
CONTRIBUTING TO NUCLEAR
PROGRESS THE WORLD OVER

# THE 1960 NUCLEAR POWER YEAR BOOK & BUYERS' GUIDE

## *NOW IN ITS 3rd EDITION*

***the Nuclear Power Year Book and Buyers' Guide is the only comprehensive publication of its kind in the world***

### CONTENTS

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An uptodate critical review of the British nuclear power scene, details of the British nuclear contracting groups and the electricity generating authorities, data on British reactors, map of nuclear energy establishments and power stations.

**2 World Authorities**
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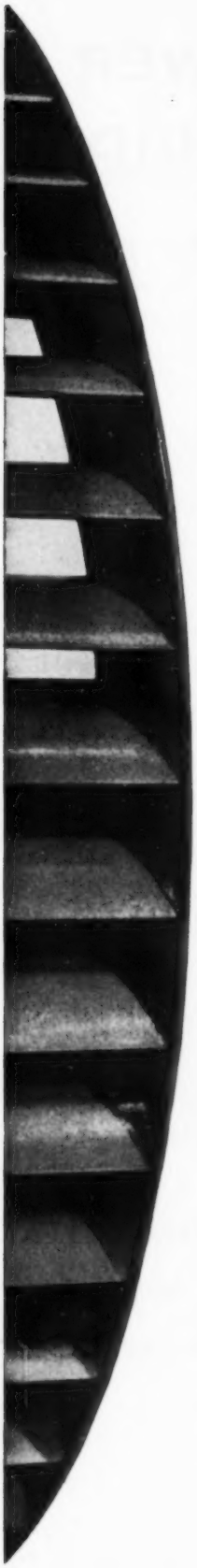
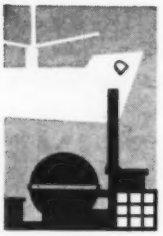
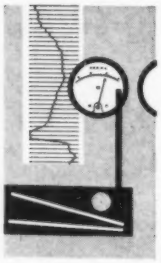


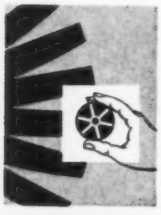
# formula for leadership



**Experience** Founded originally in 1823 the Company has had the widest experience in the design and manufacture of all types of equipment for the handling of air and other gases. Blowers, exhausters, heaters, filters, dust and fume removal equipment, and of course, fans of all types, fall within this wide scope. Fans of every size and for every purpose, from Coal Mines to Aircraft Carriers, have been designed, manufactured and tested by Keith Blackman and installed in all parts of the world—experience unparalleled in the field.



**Research** Keith Blackman's lead in design is maintained by five separate research departments. Specialised facilities are available at Tottenham for the development and testing of axial fans, centrifugal fans and filtration equipment, while a metallurgical laboratory controls the quality of materials founded at Arbroath. Tottenham also possesses one of the most advanced acoustics laboratories in the world for the investigation of sound levels in all types of fan engineering equipment.
In addition, the company's generating station, as well as supplying power to the factory, is designed to produce a wide range of A.C. and D.C. supplies for the test beds.



**Range** The Keith Blackman range covers virtually every type of fan and blower in all sizes—axial types from 5 inch to 100 inch diameter, centrifugal types ranging from 1¼ inch to 180 inch, and propeller fans from 6 inch to 72 inch diameter. Much equipment is designed for clients' specific requirements involving, frequently, the use of special materials including pvc. Other equipment is made for heating, cooling, washing, dust and fume extraction, filtration and air conditioning. *Five thousand fans of varying types are kept continuously in stock for quick delivery.*

**Keith Blackman Ltd**
(Incorporating Blackman Export Co. Ltd.)
MILL MEAD ROAD, LONDON N.17 TOTTENHAM 4522

*Leaders in the Fan Industry*

**Resources** The company's three factories cover an area of 17½ acres, and employ over 1,800 people. The main Tottenham works produces small and medium units and includes drawing offices, test facilities and machine shops, as well as the sales and administration offices.
The Arbroath works deals with the production of the larger fans. Its iron and non-ferrous foundry plant supplies the whole of the company's casting needs.
The Edmonton Factory concentrates on light sheet metal and plate work and the fabrication of steel structures.
Virtually all components, including fan motors and bearing housings, are thus designed and manufactured within the organisation—a unique combination of resources.

**Service** Through the years the company has built up an enviable reputation for service at all stages. Sales representatives are all fully trained technical men capable of giving 'on the spot' advice on routine applications or special problems. The sales organisation operates from branches throughout the country backed by a staff of qualified sales engineers at Head Office.
Despatch of stock items, of which 5,000 units are kept continuously available, is possible in as little as four days. The Company has its own road transport fleet and direct rail connections from the main factory.

TA2545/1046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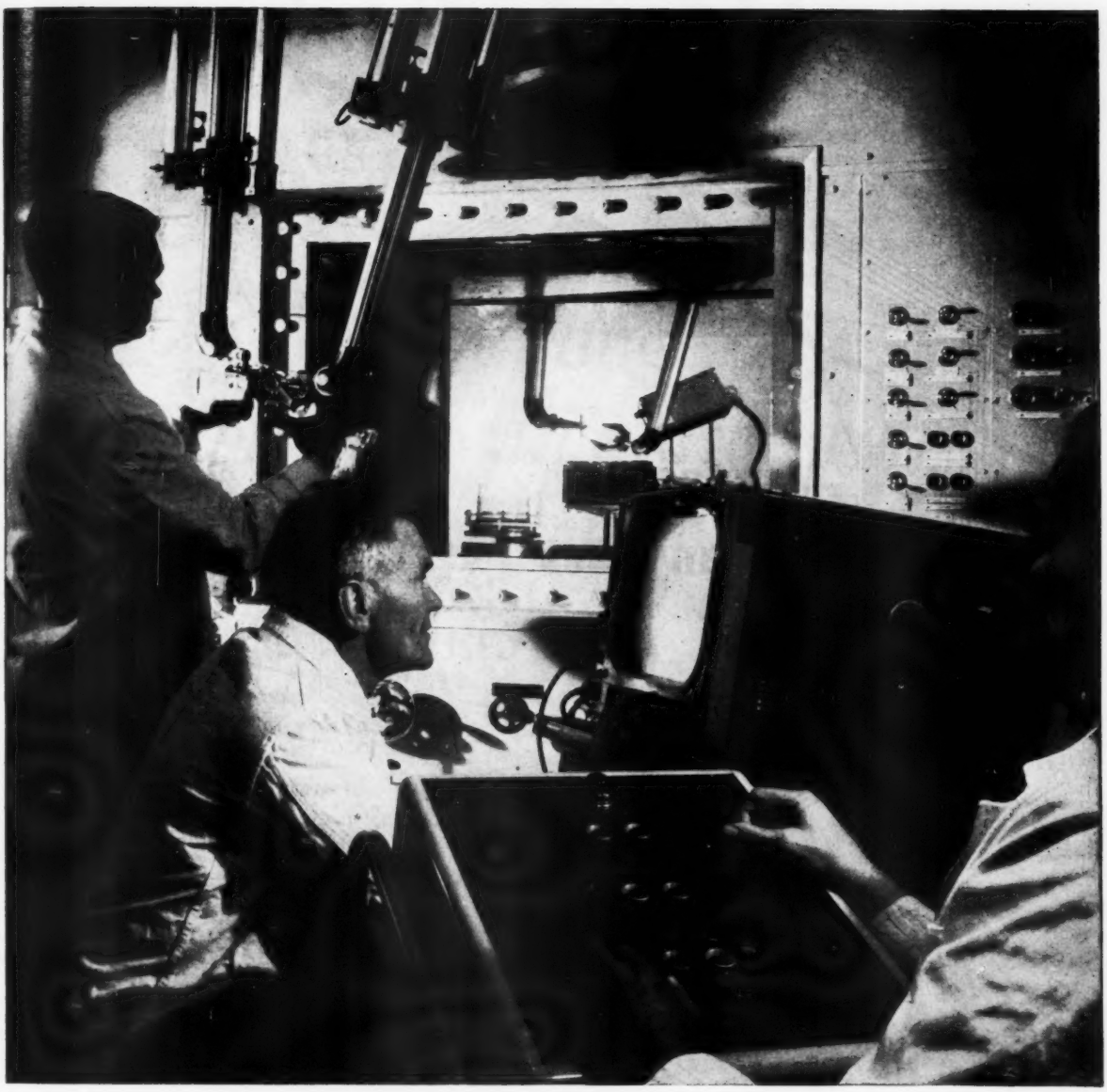

# Pye at Dounreay

The Pye Instrument Group has supplied all the equipment to the U.K. Atomic Energy Authority for the irradiated fuel element laboratory at Dounreay. In addition to supplying equipment, Pye Ltd. acted as consultants and designers on all matters in that laboratory relating to instrumentation and remote handling. The illustration above shows manipulators working in conjunction with a television camera to handle and measure a sample from the fast reactor.

*The Pye Instrument Group consists of: Pye Atomics Division; Pye Industrial Television Division; Faraday Electronic Instruments Ltd.; Labgear Ltd.; W. G. Pye & Co. Ltd.; Pye Telecommunications Ltd.; Unicam Instruments Ltd.; W. Bryan Savage Ltd.; W. Watson & Sons Ltd.*



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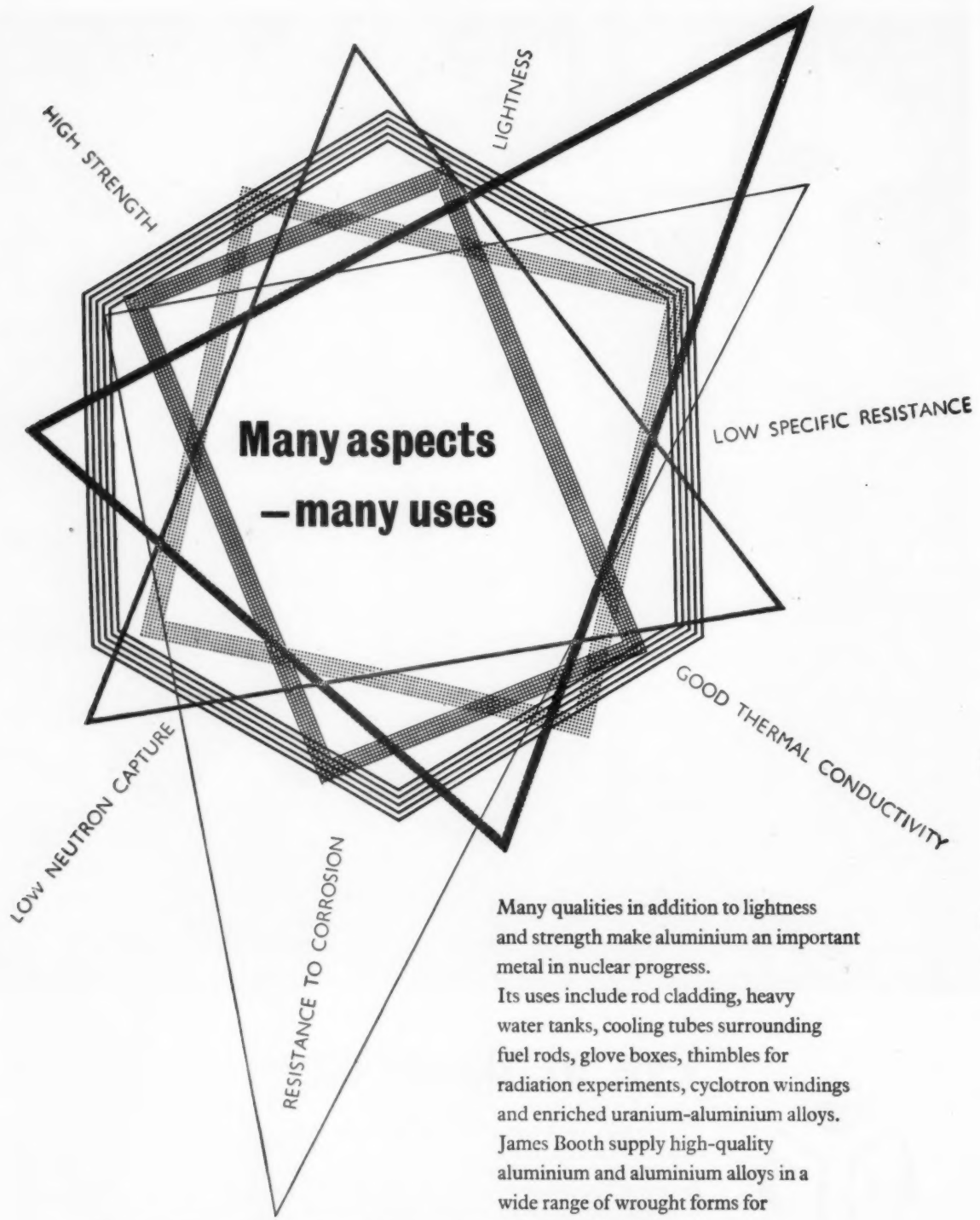


Many qualities in addition to lightness and strength make aluminium an important metal in nuclear progress.
Its uses include rod cladding, heavy water tanks, cooling tubes surrounding fuel rods, glove boxes, thimbles for radiation experiments, cyclotron windings and enriched uranium-aluminium alloys.
James Booth supply high-quality aluminium and aluminium alloys in a wide range of wrought forms for nuclear applications.

**DURALUMIN**
REGD. TRADE MARK

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EXTRUSIONS, LARGE FORGINGS, PLATE, SHEET, STRIP AND TUBES IN LIGHT ALLOYS
TGA/JBG179

# TUDOR BATTERIES

## *A wide range of equipment with a wide range of applications*

### TUDOR PRODUCTS ARE USED FOR:

Stand-by duties, e.h.t. switchgear operation, emergency and indication lighting in Power Stations (conventional and nuclear) and Sub-stations.
Stand-by duties in telephone exchanges and repeater stations.
D.C. testing in laboratories.
Emergency lighting and emergency duties, clocks and alarms in public buildings and places of entertainment (stores, banks, schools, hospitals, theatres, cinemas, dance halls, swimming baths, village halls).

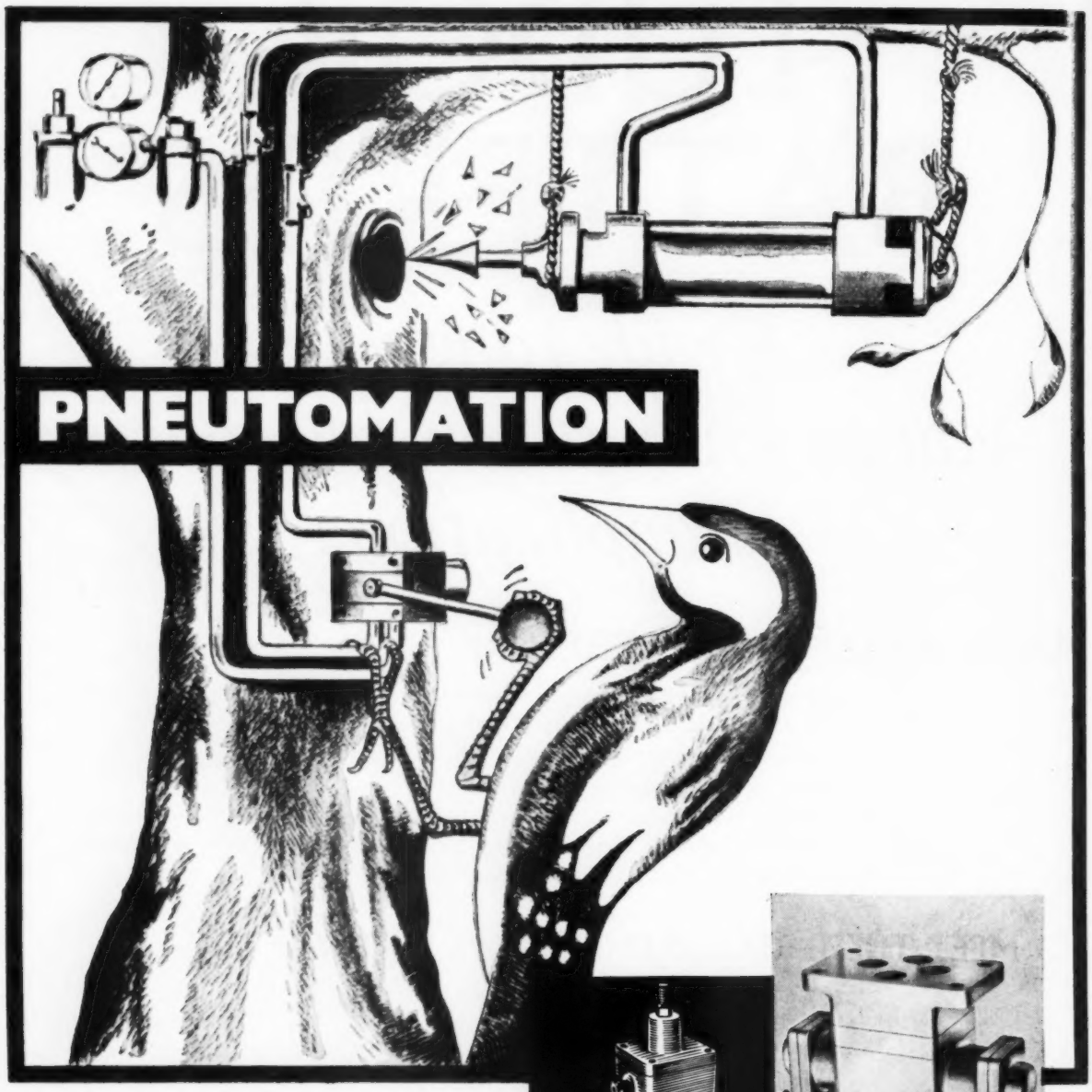
### TO MEET THESE REQUIREMENTS WE SUPPLY:

B.S.S. cells in wooden lead-lined boxes.
B.S.S. cells in open glass boxes.
B.S.S. cells in sealed glass boxes.
High Performance cells in sealed glass boxes.
A complete range of emergency lighting equipments, both self-contained and with the batteries mounted separately.
Self-contained switch-tripping equipments.
All types of chargers and associated switchboards.

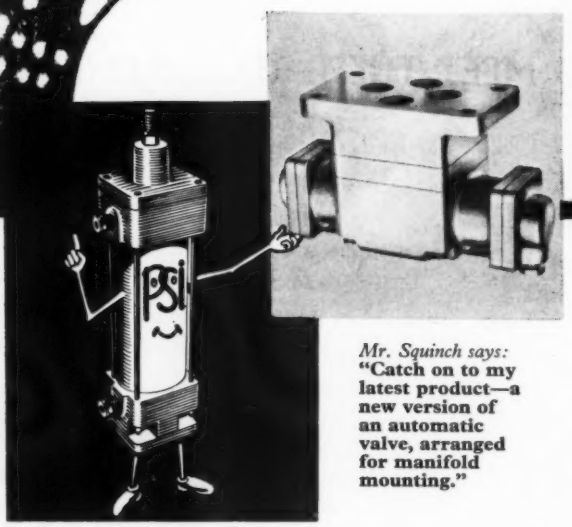
Tudor

T176

**THE D.P. BATTERY CO. LTD. MAKERS OF KATHANODE AND TUDOR BATTERIES,**
**BAKEWELL, DERBYSHIRE. BAKEWELL 581-5**




*Energy under control*—Lang Pneumatic Control eliminates human error and fatigue, raising the production level and reducing labour costs. A Lang Pneumatic power system is available for every industrial process, no matter how complicated. Every individual item has been amply proved in tests and in actual use. Design, workmanship and choice of corrosion-resistant materials ensure long, trouble-free service.




*Mr. Squinch says:* **"Catch on to my latest product—a new version of an automatic valve, arranged for manifold mounting."**

# Lang Pneumatic Ltd

(ASSOCIATED WITH DESOUTTER BROTHERS (HOLDINGS) LTD.)

**OWEN ROAD, WOLVERHAMPTON** *Tel: Wolverhampton 25221-2-3-4 Telex: 33193*

P5551

# 24

different types of fixing devices for Speed and Strength

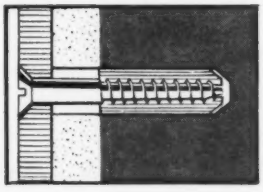
*Cut your costs with*

# RAWLPLUG FIXING DEVICES

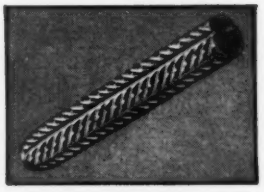
**FOR SPEEDY FIXING IN ANY MATERIAL**

No more trouble or costly delay because the material was 'difficult'! Whether it's concrete or plastic, breeze or sheet metal, cavity brick or lath and plaster, there's a Rawlplug Fixing Device that makes firm screw or bolt fixings quickly, easily and economically. The speedy answer to every fixing problem is one or other of the 24 different types of Rawlplug Fixing Devices. Write for illustrated brochure.

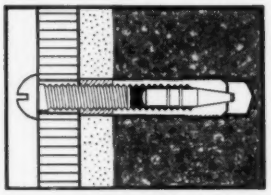
## Screw Fixings



Use the famous RAWLPLUG for neat, firm fixings in brick, stone, etc. All sizes up to $\frac{3}{4}$" diameter Coach Screws. Rawlplugs are waterproof and unaffected by climatic conditions.

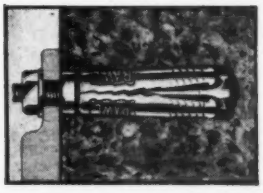


Rawlplug WHITE BRONZE PLUGS are specially suitable when the fixing is subject to very high temperatures, such as the outer brick coverings of furnaces. Use also for under-water fixtures.

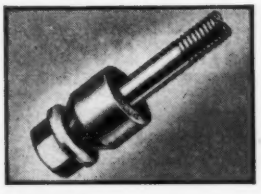


NEW! RAWLSETS, for $\frac{5}{32}$" and $\frac{3}{16}$" Whit. screws, are metal shell sockets which grip by expansion. Ideal for fixing signs, stoves, metal windows, fluorescent light fittings, etc. Write for leaflet.

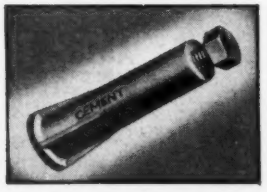
## Bolt Fixings



For bolting down machines, use RAWLBOLTS, a *dry* fixing that grips by expansion. No cold chiselling, no waiting for concrete to harden. Sizes up to 1" bolt diameter.

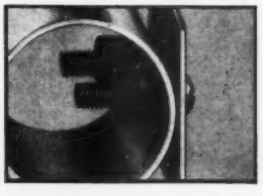


Use Rawlplug BOLT ANCHORS for bolting down in extremely wet or corrosive situations. Caulking completely seals the anchorage. Use also for anchoring Diesel Generators, Power Hammers, etc.

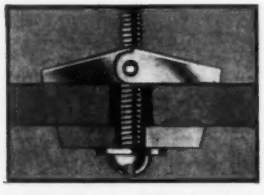



Rawlplug CEMENT-IN-SOCKETS are positioned before concrete is poured, eliminating hole-boring. They provide strong, permanent fixings wherever bolt locations can be pre-determined. For bolt diameters $\frac{1}{4}$" to 1".

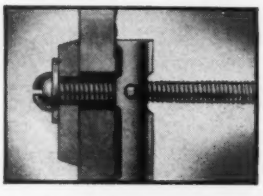
## Cavity Fixings



Screwed up from the front the amazing RAWLNUT forms its own rivet head behind the material—airtight, watertight, vibration-proof, squeak-proof! For all thin or hollow materials.



For ceilings of lath and plaster, plasterboard, etc., use Rawlplug SPRING TOGGLES. The inserted Toggle springs open behind the material, spreading the load over a wide area.



Rawlplug GRAVITY TOGGLES are ideal for hollow materials from $\frac{1}{16}$" thick. Inserted horizontally, the long end falls into correct position by gravity. The screw is then tightened in normal way. For $\frac{1}{8}$", $\frac{3}{16}$" and $\frac{1}{4}$" Whit. Screws.

RAWLPLUG

FIXING DEVICES

**USED BY THE MILLION THROUGHOUT INDUSTRY**

Made by THE RAWLPLUG CO. LTD., CROMWELL ROAD, LONDON, S.W.7

***The World's largest Manufacturers of Fixing Devices***

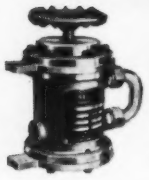
B529A

# CONTROL PROBLEMS?

## FOR GAS, AIR, OIL AND LIQUIDS

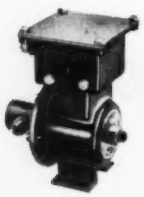
MINIATURE GAS PILOT VALVE
Size ¼" B.S.P
For use on gas/air.

FUEL OIL VALVE—
air operated
Size ¼"—½" B.S.P



CONSTANT FLOW VALVE
for controlling flow of fuel fed by ring main systems.

OVERHEAD HEATER VALVE
Size ⅜"—½" B.S.P



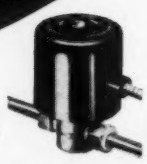
3-WAY AIR VALVE
ADMIRALTY pattern
otherwise as TW/HP/AC.
Size ¼", ⅜", ½" B.S.P

## WE KNOW THE ANSWERS

3-WAY VALVE diaphragm operated suitable for use on hydrogen at pressures up to 22,000 p.s.i.
Size ¼", ⅜", ½" B.S.P

**BLACK**
**AUTOMATIC CONTROLS LTD**

DIFFERENTIAL PRESSURE SWITCH
Pressure 300 p.s.i.
Temperature 250°C



FUEL OIL VALVE
Size ¼"—½" B.S.P
Pressures up to 500 p.s.i.g.

FLOW SWITCH
Standard model size
¼" B.S.P —¾" B.S.P
Other models in sizes up to 14"

FUEL OIL VALVE
Size ¼"—½" B.S.P. High pressure, high viscosity.

The range of solenoid and diaphragm operated valves and pressure switches developed by Black Automatic Controls is finding a rapidly increasing acceptance in modern industry, including the missile and nuclear energy fields.
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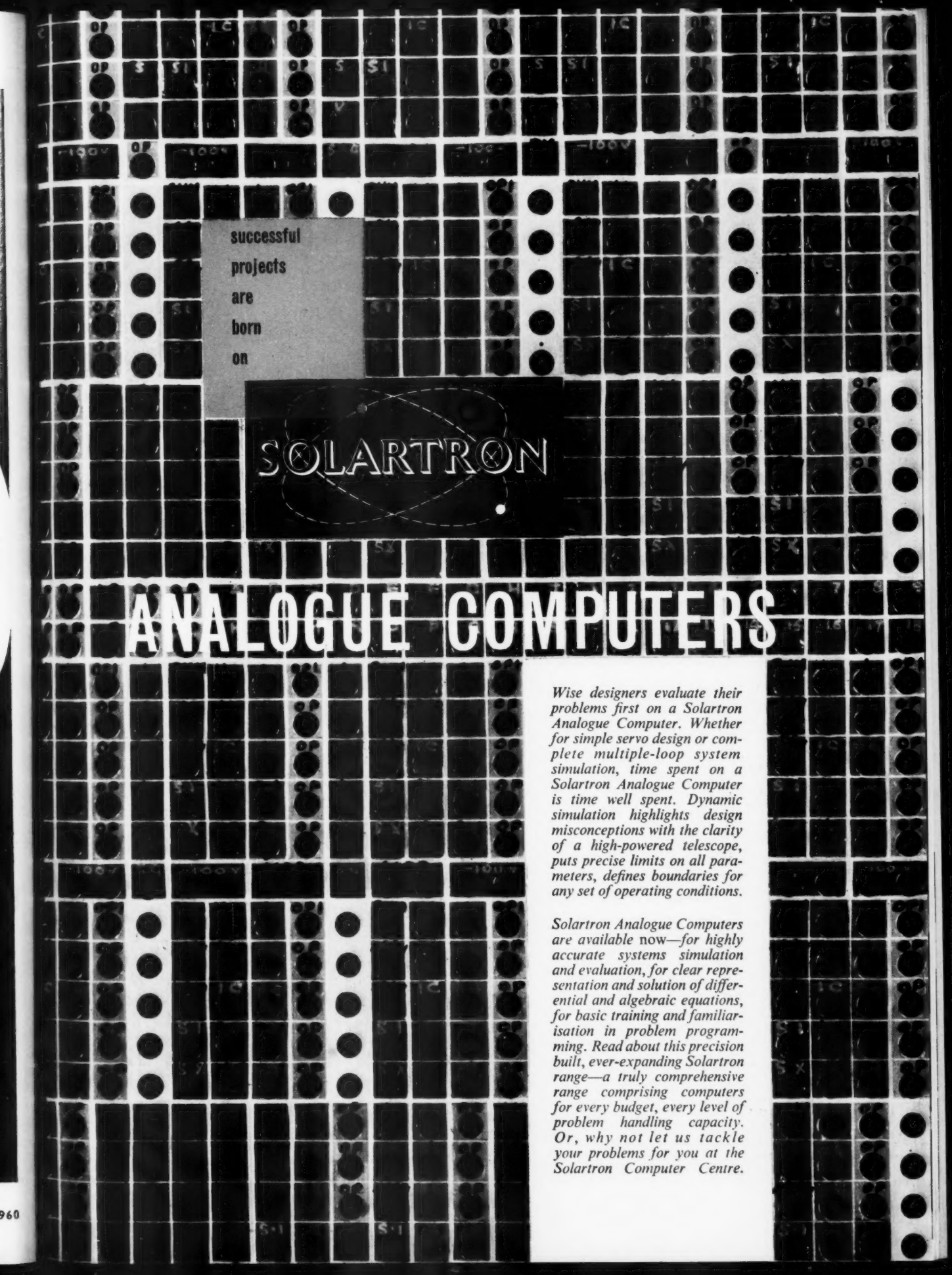


*Wise designers evaluate their problems first on a Solartron Analogue Computer. Whether for simple servo design or complete multiple-loop system simulation, time spent on a Solartron Analogue Computer is time well spent. Dynamic simulation highlights design misconceptions with the clarity of a high-powered telescope, puts precise limits on all parameters, defines boundaries for any set of operating conditions.*

*Solartron Analogue Computers are available* now—*for highly accurate systems simulation and evaluation, for clear representation and solution of differential and algebraic equations, for basic training and familiarisation in problem programming. Read about this precision built, ever-expanding Solartron range—a truly comprehensive range comprising computers for every budget, every level of problem handling capacity. Or, why not let us tackle your problems for you at the Solartron Computer Centre.*

960

SOLARTRON

training

research

full scale

any size

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AMONG THE USERS OF SOLARTRON COMPUTERS ARE

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*Hawker Siddeley Group*

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*C. A. Parsons*

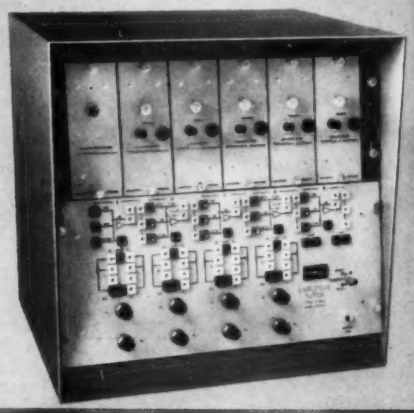
*Royal Aircraft Establishment*

*U.K.A.E.A.*

*United Steel*

## 1 analogue tutor

**Capable of demonstrating any form of second-order differential equation. Applications include representation of servos, simple electrical networks, motion of particles and like systems.**



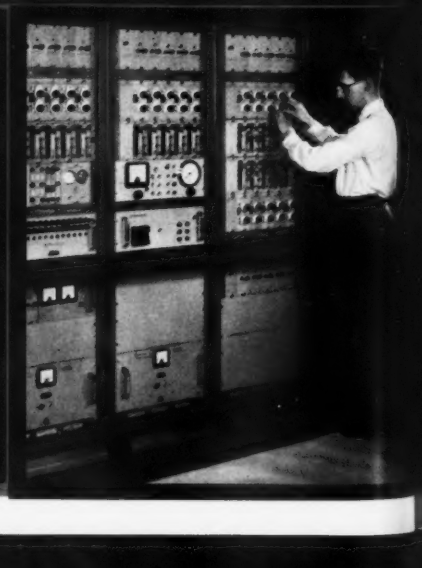
* A co.plete miniature computer for Student use

**It is safer and cheaper to simulate mistakes than make th Without having to build it, here is your projected sys brought to your very desk-side or laboratory!**

**The Solartron SPACE '30' analogue computer (right) is unique in flexibility of application. With an operational capacity greater than many computers using 40 or more amplifiers, SPACE '30' has an additional problem-beating complement of non-linear units for direct analogue simulation of almost any dynamic system. Even when many complex system elements must be included as analytic or empirical non-linear operators, SPACE '30' will faithfully simulate according to the known information to produce a highly accurate prediction of dynamic performance.**

## 4

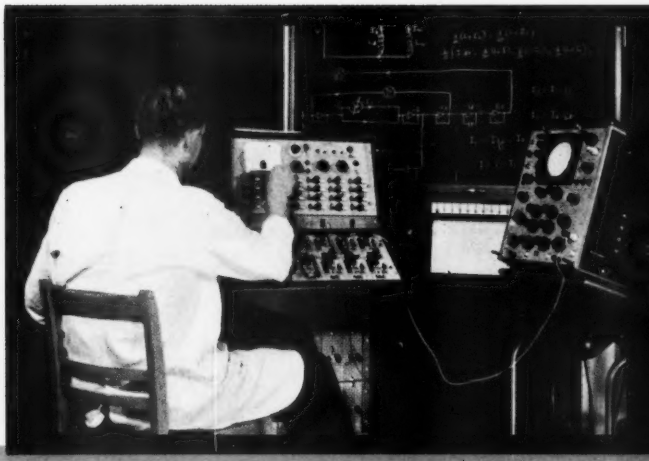
**All Solartron analogue computers are built using a highly flexible modular construction technique. Thus at any time, your Solartron machine need only be as complex as budget and work demand. Special machines, like the Auto-Control Simulator illustrated here, or the SPACE '30' series, can be expanded or multiplied at a moment's notice.**



# ANALOGUE COMPUTERS

The Analogue Computer is the foremost aid to training in feedback techniques and theoretical servo analysis, also for clearly representing and solving complex differential equations.
Because of its common basic approach to all dynamic problems, analogue computing practice is vital to broadening engineering appreciation. Parallels between widely different systems are drawn with sudden lucidity — between hydraulic controls and national economics for example, or between a nuclear reactor and a controlled biological culture. Every problem solved on an analogue computer brings a wealth of dynamic knowledge, relevant to wide areas of subsequent work.

MINISPACE * Provides high accuracy at low cost * Ideal for servo simulation and basic reactor studies for students. * Eminently suitable for sub-programming larger machines.



## 2 minispace

★ Solves linear or non-linear problems: up to 5th-order differential equations.

★ Easily expanded to greater problem capacity.

For handling even bigger problems, your SPACE '30' installation can be multiplied to give 60 or 90-amplifier capacity—or, in the preferred case, you can choose a SPACE '60' or SPACE '90' machine, each fully integrated for centralised programming and control.

## 3 space '30'

★ 30 amplifiers in new, optimised design configuration.

★ Full complement of non-linear computing elements.

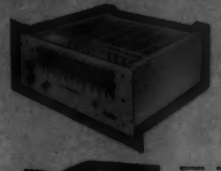
★ The first choice for complex dynamic simulation of any kind.

★ Easy to use — easily expanded.

## FOR INDEPENDENT USE

These three Solartron Analogue Computing Units are typical of many which exist in their own right as precision instruments and which are immediately available for use independently, or in existing analogue computing installations.

*Full technical literature is available on request.*



- 12-Segment, high accuracy function generation. ± 100 V output, 0.5% long-term stability.
- Rapid, accurate break-point setting in Cartesian co-ordinates, by digital volt-meter.

## 5 diode function generator TR 829

- Fastest response available: accurate t.s.d. up to 10 c/s.
- Six-section pot, driven directly from servo.
- Self-contained with transistor feedback amplifier and power supply.
- Multiplies up to five variables by one other or generates up to sixth power.

## 6 servo multiplier TJ 725

- 0.005% limit on deviation between positive and negative 100V supplies. NPL certificate on request.
- Better than 0.1% long term accuracy and 4,000 to 1 stability ratio.
- Incorporates Weston cell as reference source.

## 7 precision reference power supply AS 756/2

THE SOLARTRON Computer Centre at the Dorking Research and Development Laboratories of the Solartron Group offers comprehensive facilities for dynamic problem evaluation, programming and detailed solution on SPACE '30' Analogue Computers. Skilled personnel will, if you require, translate your problems into computer language and carry out all the operational procedures.

SOLARTRON COMPUTER CENTRE

*address your enquiries to:*

**THE SOLARTRON ELECTRONIC GROUP LIMITED (Computer Division)**

**Victoria Road, Farnborough, Hampshire. Telephone: Farnborough (Hants) 3000**

*Illustration depicts subjecting materials to neutron and gamma radiation in cryogenic environment.*

# NUCLEAR EXPERIENCE AT YOUR SERVICE

Lockheed Nuclear Products today offers a compact knowledgeable organization well qualified to provide these services in nuclear fields:

*Reactor design*
*Facility design and operation*
*Instrumentation*
*Shielding*
*Radiation effects*
*New isotopes applications*
*Meteorology*

*Some things Lockheed Nuclear Products is doing:* Operating the world's unique research facility, the Georgia Nuclear Laboratories, at Dawsonville. (These were designed and built by Lockheed for the U.S. Air Force.)

Producing a cryogenic test loop for installation in the National Aeronautics and Space Administration's Plum Brook reactor.

Participating in experiments to study effects on space vehicle materials operating in a combined nuclear and cryogenic environment.

Producing a portable pool-type reactor for the Atomic Energy Commission.

Building a Lockheed Nuclear Products-designed 10 kw training reactor for Ohio State University... conducting theoretical shielding studies for the U.S. Army.

Lockheed Nuclear Products offers the best in nuclear products for *space* ... for *industry* ... for *defense.*

# LOCKHEED
## NUCLEAR PRODUCTS

Georgia Division: Dawsonville, Marietta, Atlanta • *Lockheed Aircraft Corporation*



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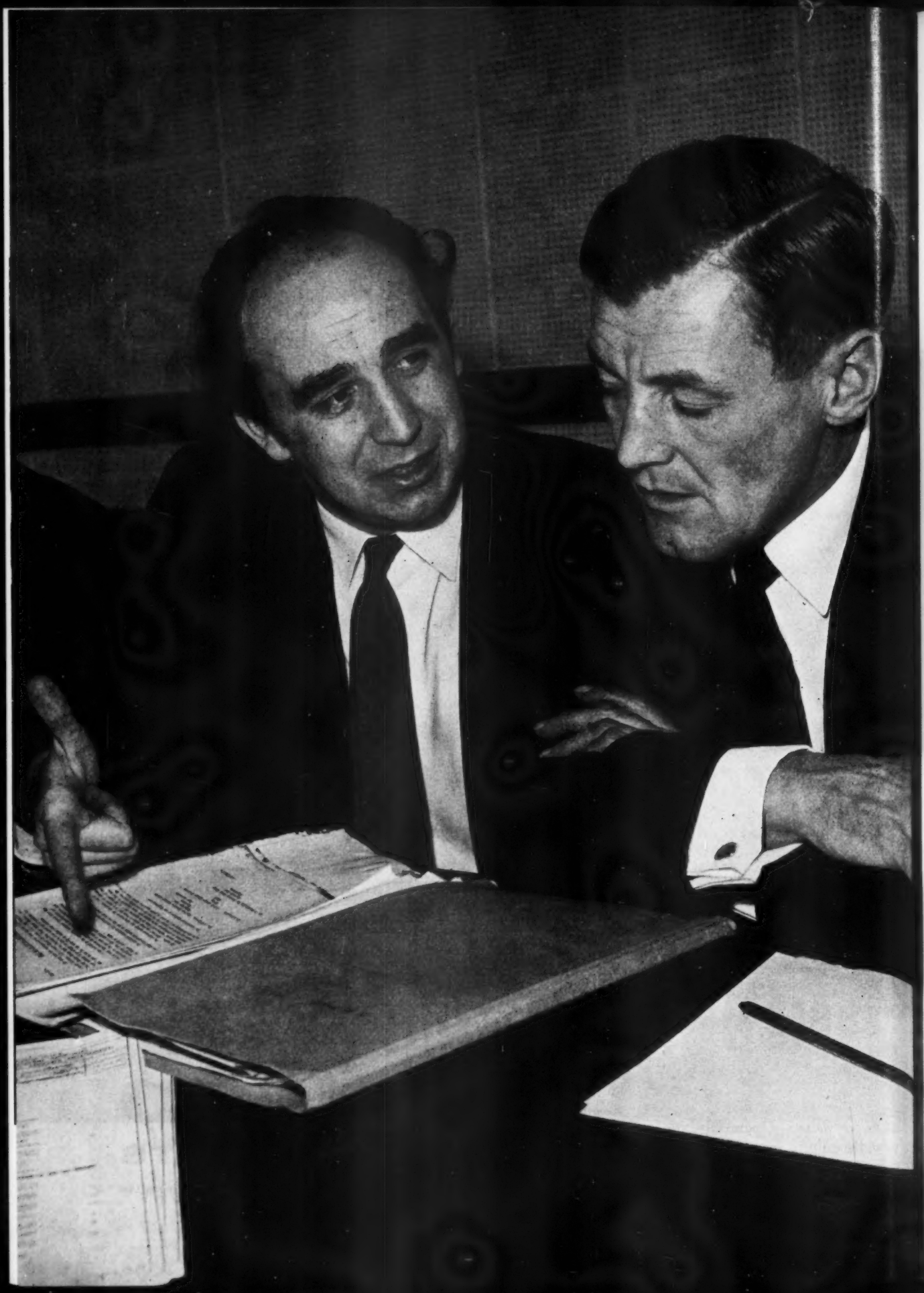

# I happen to know a little

# about that subject, sir . . .

He will not immediately be promoted to the board of the company or given an extra five hundred a year. But he has put the committee right on a technical matter and demonstrated in the process that his reading is thorough and broad—a useful point to make.

*Nuclear Power* is published for men like this. In one year's issues* it covers an enormous range of techniques and equips its readers with concise and technically authoritative details of theory and practice outside the normal confines of their own specializations.

*Why not start *your* index file of likely-to-be-useful data from *Nuclear Power*? A pre-paid subscription card will be found facing " Opinion ". Send it now and you will be in time for next month's issue.

# A new range of Industrial Ceramics

Union Carbide* Unamic Ceramics fill the long-felt need for a class of refractory materials which operate above 1000°C with almost no dimensional change. They have been developed for arduous conditions where high dimensional accuracy is required over a wide range of temperature and where high resistance to thermal shock is necessary. There are, at present, three standard Unamic ceramics developed for different types of applications. Unamic 19 ceramic has exceptional thermal shock resistance; because of this and its chemical stability, it is suitable for use in contact with many molten metals. Unamic 25 ceramic is used for components requiring exceptionally close dimensional tolerances. Its low coefficient of thermal expansion means that the dimensionals remain the same at elevated temperatures and also gives excellent thermal shock and fatigue resistance. It also has good mechanical strength which is maintained at high temperatures. Unamic 255 ceramic is designed for components requiring elevated creep resistance up to at least 1200°C. It has good thermal shock resistance and the same high dimensional tolerances and strength as Unamic 25. For special applications where specific combinations of properties are required, non-standard Unamic ceramics can be produced. Please write for the booklet 'Unamic' which gives further details of the new range.

UNION CARBIDE

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CBC

# The Problem...

## ...EVACUATING AND WELDING COMPLETE ANEROIDS IN ONE OPERATION!

This unretouched photograph shows aneroids, supplied by kind permission of Messrs. Appleby & Ireland Limited, welded on the "SPEEDIVAC" unit.

# The Solution...

## "SPEEDIVAC"

## ELECTRON BEAM VACUUM WELDING UNIT

Always a difficult process, the completion of an aneroid usually involves two distinct processes—welding and final evacuation. With the "SPEEDIVAC" electron beam welding unit* this can be achieved in one cycle as components are welded under a high vacuum and the process is complete when the final weld has been made.

Absolute pressure capsules are just one example of how this new technique can simplify production difficulties. Electron beam welding will produce the highest quality flux-free welds with an atmospheric purity better than one part in ten million.

*CEA systems, patent pending (Brit. pat. appln. 1962/57)

**EDWARDS HIGH VACUUM LTD** · MANOR ROYAL · CRAWLEY · SUSSEX · ENGLAND · *Crawley 1500*



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# CHESTERFIELD

## FIRST WITH BERYLLIUM TUBES

## NOW

## FIRST WITH FINNED BERYLLIUM TUBES

This is 0.295"B
with wall thickness
of 0.040" It has 18 radial fins
0.040" wide x 0.060" high

FIRST BERYLLIUM CHESTERFIELD TUBE CO. LTD. ENGLAND

THE CHESTERFIELD TUBE COMPANY LIMITED · CHESTERFIELD · ENGLAND · A MEMBER OF THE TI GROUP

CRC 69

# RIO TINTO

*Rio Tinto, producers of uranium and thorium, will play an important part in the future industrial use of nuclear power through the following companies:*

**Rio Algom Mines Limited,** CANADA
has amalgamated the four Canadian uranium mining companies under Rio Tinto's management to form the largest uranium producing company in the world.

**Thorium Limited,** UNITED KINGDOM
owned by Rio Tinto and Dow Chemie A.G., processes crude thorium materials and markets a variety of refined thorium and rare earth compounds.

**Mary Kathleen Uranium Ltd,** AUSTRALIA
managed by Rio Tinto in Australia, is now in full production and supplying uranium oxide for Britain's nuclear power stations.

**Nukem—Nuklear—Chemie und—Metallurgie G.m.b.H.,** GERMANY
has been formed by Deutsche Gold-und Silber-Scheideanstalt (Degussa), Rio Tinto and Mallinckrodt Chemical Works to manufacture nuclear fuel materials and fuel elements.

**Rio Tinto Dow Limited,** CANADA
Rio Tinto and the Dow Chemical Company of Canada are collaborating in uranium processing and producing thorium as a by-product of uranium.

**Austro-Chematom Kernbrennstoff G.m.b.H.,** AUSTRIA
formed by Osterreichische Stickstoffwerke A.G. in association with Rio Tinto and Degussa to manufacture nuclear fuel materials and fuel elements.

**Rio Tinto Management Services (U.K.) Limited**
BARRINGTON HOUSE, 59 GRESHAM STREET, LONDON, E.C.2




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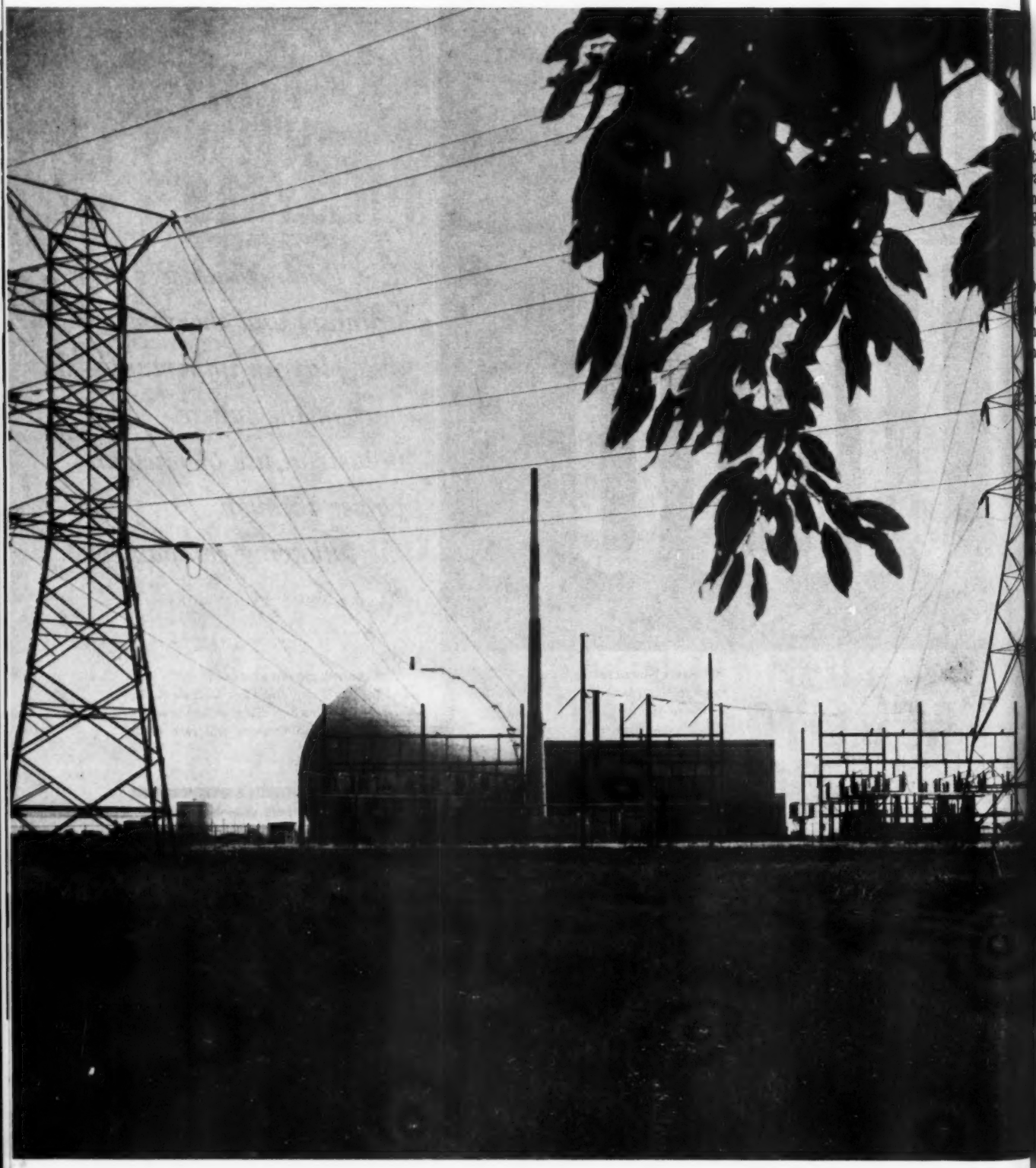
*Report from the General Electric Company, U.S.A.*—*

U.S.A.

# GENERAL ELECTRIC COMPLETED OR OPERATING NUCLEAR POWER PL



# TEDRESDEN, WORLD'S LARGEST VEPLANT, AHEAD OF SCHEDULE

## Dresden Station Of Commonwealth Edison Co. Provides Electricity Using General Electric BWR

lthough in full-power operation since June, 1960, on ctober 12, 1960, near Chicago, Illinois, U.S.A., the Dresden ation—world's largest operating nuclear power plant—as formally dedicated "to the peaceful use of atomic nergy." Designed and built by General Electric, the new 0,000 kilowatt Dresden Station is a major achievement nuclear progress.

When General Electric signed the contract to build the resden project in 1955 there was no comparable installaon in existence. With no precedent for such an undertakg Dresden truly represents a world "first" for private dustry.

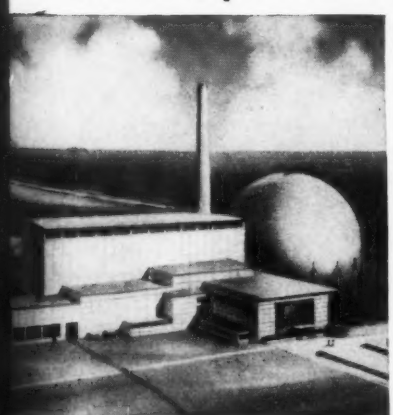
The feasibility of BWR's has been proved by the successul operation of the Dresden station. The Dresden reactor ore is especially stable even at void contents greatly in xcess of design. Peak to average heat flux in operation as 15% lower than design values. Response to operator ontrol in all cases was as specified, with load following ompletely automatic from 55 to 100 percent of full load. adioactivity in the steam and condensate systems of the lant were significantly less than contemplated in design. Maintenance in all parts of the plant to date is restricted only by thermal cooling periods rather than radioactive cooling.

The significance of this report: initial operating results confirm the General Electric boiling water reactor concept as the greatest potential source for competitive nuclear power in the shortest possible time. As a result of Dresden's success, boiling water reactor plants larger than 400 megawatts are now under development. The General Electric BWR in large-scale operation at Dresden will continue to provide much of the data that will stimulate utilization of nuclear power to meet growing demands for energy in the world today.

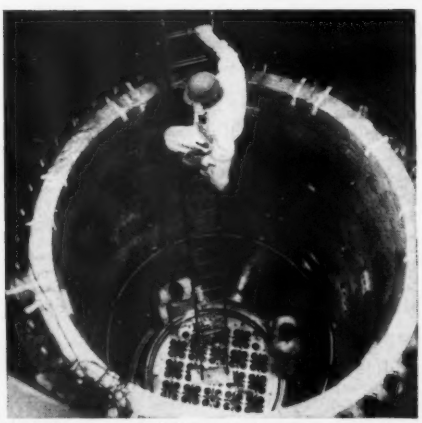
Let General Electric's extensive atomic facilities and experience in the nuclear power field help you in the application and technical advancement of atomic energy. For further information contact *International General Electric S.A., Dept. 30-12, 81, Route de L'Aire, Geneva, Switzerland* or write: *International General Electric Company, Dept. 30-12, 150 East 42nd Street, New York 17, New York, U.S.A.*

*General Electric Company, U.S.A. is not connected with the British company of the same name.

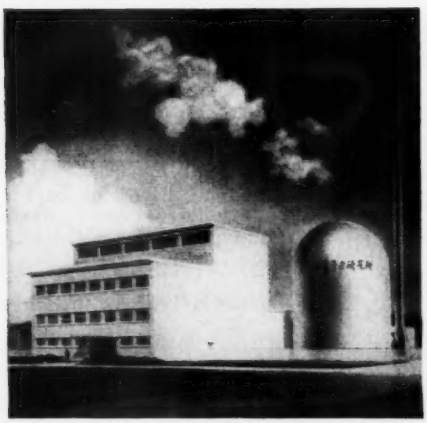
## Latest Report On Other General Electric BWR Plants Around The World



er Naples, Italy—the Garigliano Nuclear Power Plant der construction for the Societa Elettronucleare zionale (SENN). The General Electric BWR will deliver 0,000 kw of nuclear power at a lower cost per KWH an all eight other reactor concepts considered.



Kahl, Germany—Technicians check out the assembly of the boiling water nuclear reactor for West Germany's first atomic power station. The components for the 15,000 kw single-cycle BWR nuclear steam supply system were designed by General Electric.



Tokai-Mura—Japanese Atomic Energy Research Institute and General Electric Japan, Ltd. sign contract to provide a 12,500 kw BWR plant. This plant, designated JPDR, is the first enriched uranium power reactor ordered by Japan.

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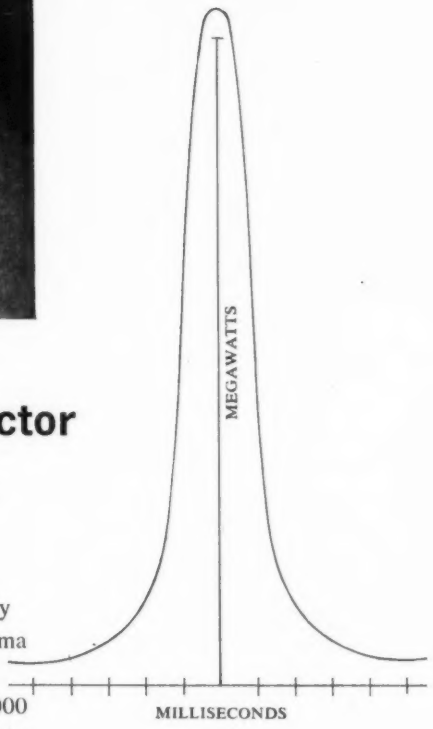
*TRIGA Mark-F now in operation at General Atomic.*

# The TRIGA Mark-F Pulsing Reactor




General Atomic Division of General Dynamics Corporation is pleased to announce a new addition to its TRIGA family of reactors—the TRIGA Mark-F Pulsing Reactor.

The TRIGA Mark-F, developed by General Atomic, is especially designed to yield short reproducible pulses of neutrons and gamma rays for use in nuclear effects research and testing. It is capable of being pulsed repetitively to peak power levels of over 2,000,000 kilowatts with half-maximum pulse widths of 10 msec, owing to the inherent characteristics of the TRIGA reactor's unique uranium-zirconium hydride fuel elements. During pulsed operation, a maximum flux of $6 \times 10^{16}$ neutrons/cm$^2$-sec. can be achieved. The Mark-F design permits variation of neutron to gamma dose ratios by a factor of ten and provides for a large, easily accessible exposure window immediately adjacent to the core.

A prototype of the TRIGA Mark-F was placed in operation the summer of 1960, and construction of two such reactors will be completed in 1961 for the United States Government, including one for the U.S. Army's Diamond Ordnance Fuze Laboratories. Other versions of the TRIGA include the TRIGA Mark I and Mark II reactors—for training, research and isotope production—which are now in use, or soon will be, on five of the six continents.

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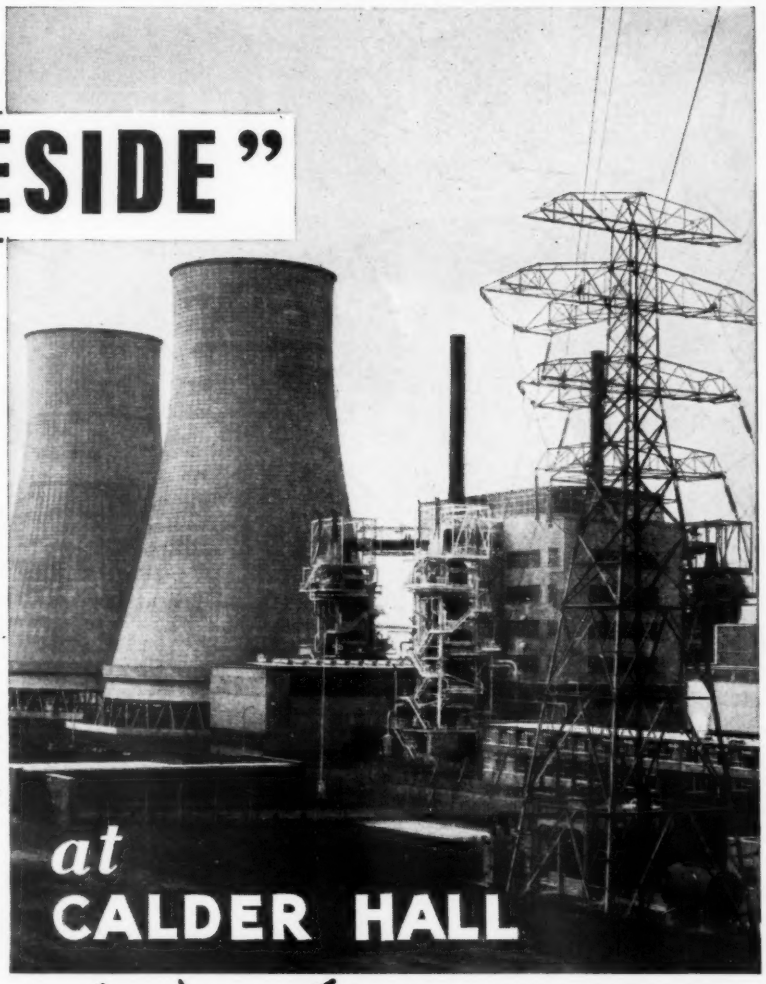


*Photo by courtesy U.K. Atomic Energy Authority*

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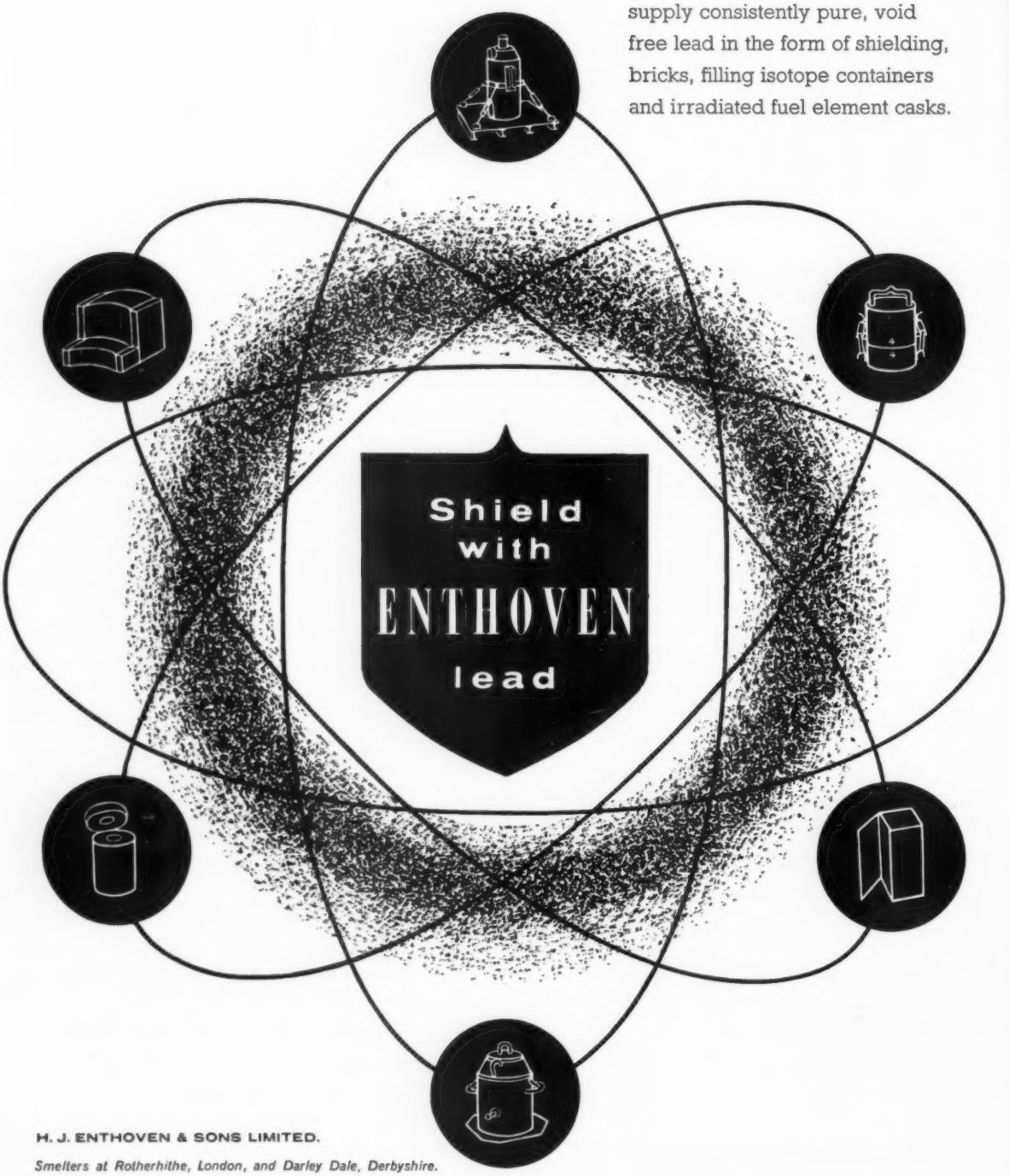


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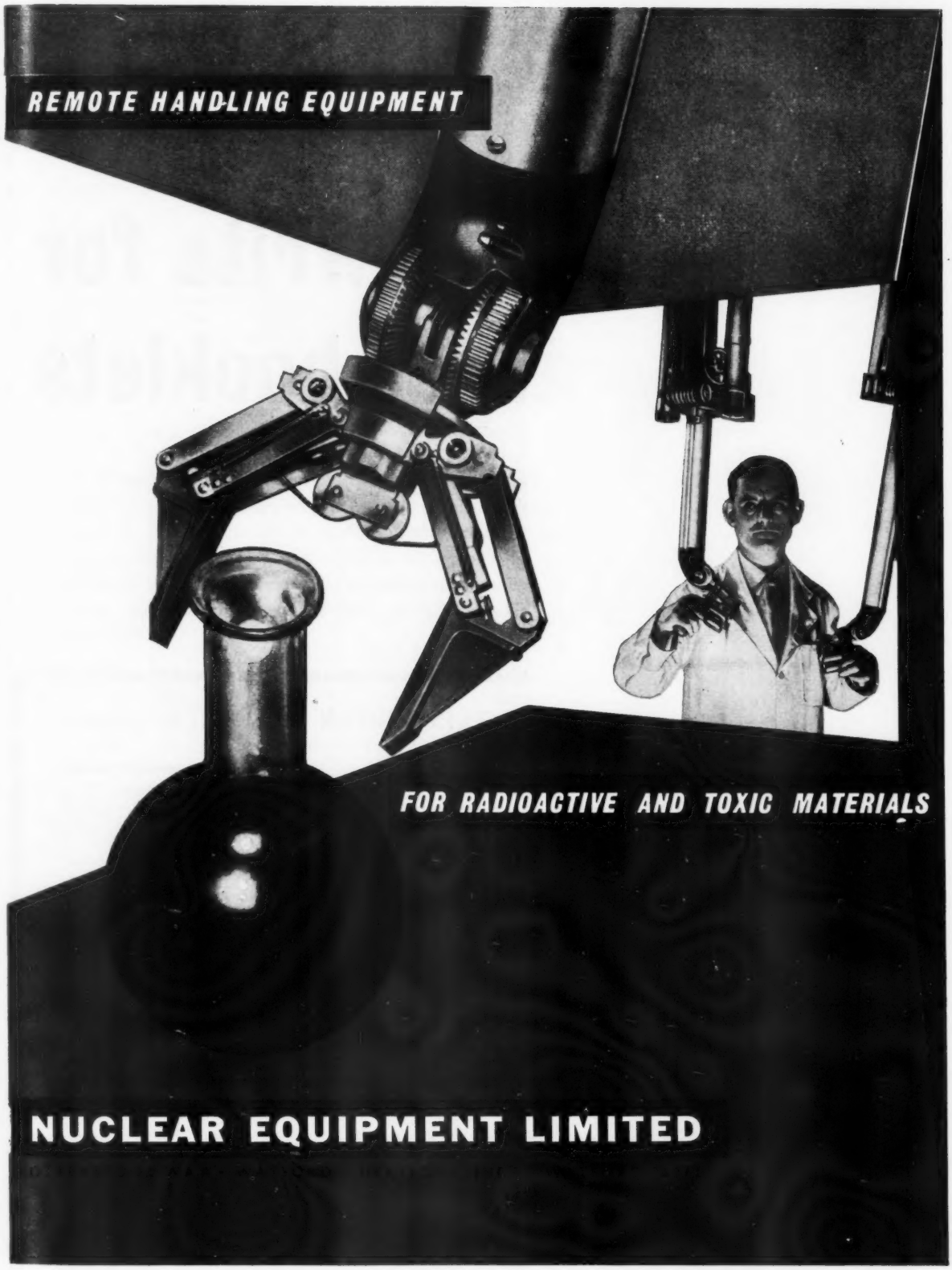
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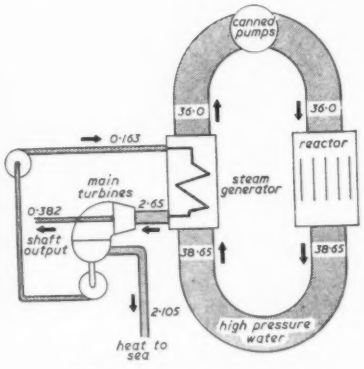
Nuclear Power
REACTORS MATERIALS INSTRUMENTATION PROCESSES IRRADIATION
DECEMBER 1960 VOLUME 5 NUMBER 56

# VIEWPOINTS *letters to the Editor*

## Marine reactors

SIR: In Messrs. Thomas and Lorge's interesting article in your October number, they described the marine reactor designed by Rolls-Royce Limited which was first presented to the Galbraith Committee by Vickers Nuclear Engineering Ltd.

The article gives a heat stream diagram showing that most of the heat passes through the reactor circuit without doing useful work, but rightly points out that the relative width of the streams depends on the datum.




PWR heat stream diagram

The figure above shows a similar diagram for a typical PWR, the numbers showing approximate heat flow in Btu/h $\times 10^8$, feed heating and all losses being neglected. It will be seen that the ratio of maximum heat in the stream for the shaft output is 100 for the PWR. In the Steam Cooled Reactor, using the figures in the article, it is less than 21. In BWRs there may be natural or forced circulation, external or internal. In any case, the water will probably pass through the core five or six times.

In theory, a BWR could be built as a once-through boiler but in practice this would be hazardous. Taking the maximum thermal efficiency that this type of reactor can give, the ratio of the total heat passing out of the core to the shaft outlet is about 36 to 1. The fact that the circulation may be inside the pressure vessel in the BWR and is external in the Steam Cooled Reactor, makes little difference provided the heat insulation is good.

Even the Gas Cooled Reactor driving a gas turbine directly requires a recuperative heat exchanger to get a reasonable efficiency and much of the heat, again like music in the song, goes roun' an' aroun'. Thus, almost invariably most of the heat passes through the reactor circuit without performing useful work but less so in the V.N.E. seaworthy reactor than in most other types.

CAPTAIN H. F. ATKINS,
*Vickers Nuclear Engineering Ltd*

## French oscillator research reactor

SIR: In your *Worldview* article 'New Winfrith research reactor', October issue, you state that Hector 'is believed to be the first (zero energy oscillator research reactor) in which oscillator measurements can be carried out over such a wide range of experimental conditions'. May I point out that the research reactor, Minerve, at the Centre d'Etudes Nucleaires de Fontenay-aux-Roses, went critical in October 1959 and was specially designed to perform cross section measurements on absorber or fissile materials by using the pile oscillator technique.

The reactor, of the pool type, is also capable of carrying out measurements over a range of conditions comparable to that of any power reactor. Neutron energy distributions are modified by changing the dimensions of the central sample-containing chamber or by packing the chamber with graphite or heavy water.

R. VIDAL
*Service des Experiences Critiques*
*Centre d'Etudes Nucleaires*

## Eldorado Mining and Refining

SIR: I should like to enlarge upon a small news item in your October issue: 'Canada—Eldorado Mining and Refining Limited's mine has been closed down'.

So that your readers may not be misled into thinking that our company is no longer engaged in the mining of uranium, I hasten to explain that it still operates a large mine and mill in the Beaverlodge area of Northern Saskatchewan and is a leading Canadian producer of uranium yellow cake.

Eldorado's smaller mine and mill at Port Radium on Great Bear Lake in the North West Territories did close down because economic ore reserves had been all but exhausted. Incidentally, this mine, in operation since 1930, was the oldest uranium mine on the North American continent and provided, during its early history, radium which broke the Belgian monopoly on this commodity and, later, much of the uranium so vital to the early atomic energy developments.

*Eldorado Mining and Refining Limited*
*Port Hope, Ontario*
G. C. BROWN
MANAGER

## AGR liaison

SIR: I was very surprised to see in your November issue comments by Gracchus on the release of information by the AEA to industry on the Advanced Gas Cooled Reactor system. I am not sure whose cause Gracchus intended to champion: surely it could not be that of the Consortia who collaborate with the AEA on gas cooled reactors. At regular meetings of the Consortia and the AEA, many problems of the AGR, particularly the fuel elements and graphite, are discussed in detail and advance information passed over. The flow of information is not one way. The Consortia are working on the solution of some of these problems, either at their own expense or under contract from the AEA, and are making a useful contribution to the development of the system. In addition to the regular meetings, continuous contact is maintained between the parties on all important matters. Also, the Consortia have seconded engineers to the AGR team at Risley to work on specific plant items.

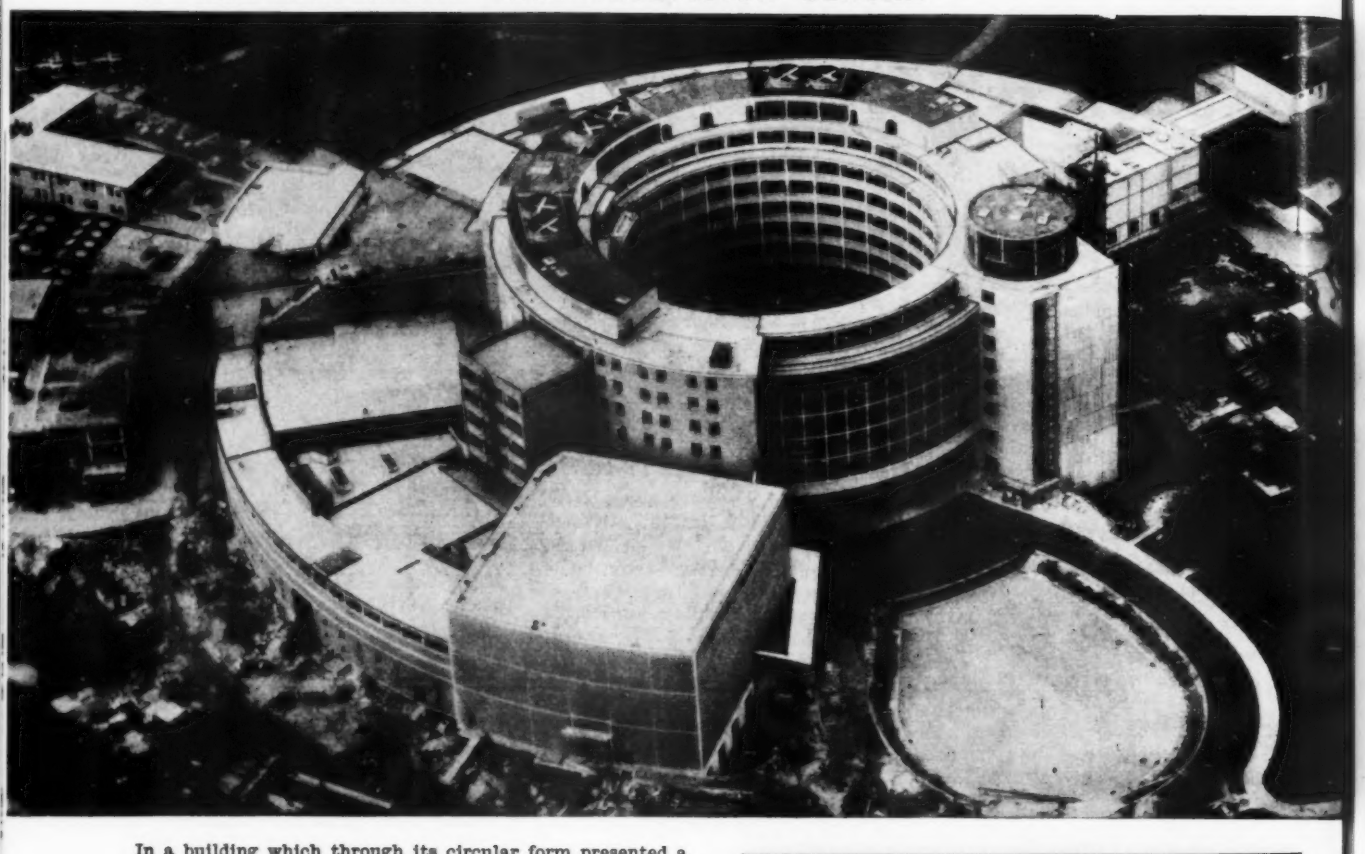
The exchange of information may not be perfect—what system is?—but there is very little that a responsible engineer could criticize.

*The Nuclear Power Group* S. A. GHALIB

*GRACCHUS writes: I was championing no one but simply recording a feeling I had noted in some (responsible) sections of industry. Other persons have rushed to champion the AEA's liaison on the AGR and it appears the majority are happy with existing arrangements.*

# UNISTRUT

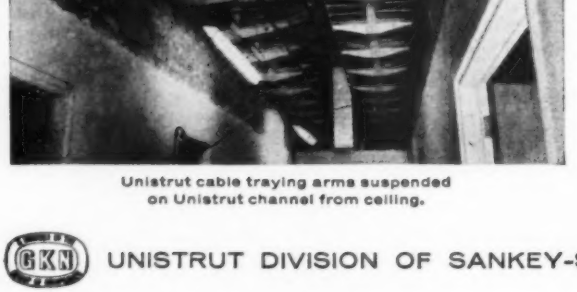
## AT THE BBC WOOD LANE TELEVISION CENTRE



In a building which through its circular form presented a number of installation problems, a new type of Unistrut cable traying arm and the familiar concrete insert (over 3 miles of which have been used throughout the buildings) provide further examples of the versatility of Unistrut.
The traying arms support many miles of coaxial cable carrying sound and vision signals from the nine studios within the centre and from outside sources including Eurovision. The cables descend at frequent but irregular intervals, often in batteries of 400 at a time, to the various equipment bays.

### MAXIMUM EASE OF ACCESS

The new Unistrut cable traying arms allow closer spacing with greater ease of access than standard arms previously available, and are suspended from the building structure using standard Unistrut channel and self-locating nut assembly for speed and rigidity.



Unistrut cable traying arms suspended on Unistrut channel from ceiling.

The 250 yd. ring duct under construction. Unistrut concrete inserts were built in at this stage.

### RING DUCT WITH CONCRETE INSERTS

Main services are carried below the building in a ring duct approximately 250 yards long with Unistrut concrete inserts embedded, at 2 ft. centres, during the pouring of the concrete. This eliminated the need to pierce for the thousands of fixings required; the cables resting on Unistrut components bolted directly into the inserts—again using the rapid, easily-aligned self-locating nut assembly. The inserts are able to carry a total U.D.L. of about 800 tons, thus limiting the cost of any future expansion required.

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# OPINION

## New drive on magnox reactors

THE NEW DETERMINATION of the Central Electricity Generating Board to insist that its 'invitations' to each of the Consortia to submit a fully detailed tender for each future magnox nuclear power station be regarded as compulsory, seems to represent its first reaction to the hold-up on the Advanced Gas Cooled Reactor. Though the Atomic Energy Authority continues to battle grimly with its recalcitrant system and has overcome some of the more formidable technical problems, each of its succeeding cost estimates reduces the AGR's advantage over the magnox reactors.

These technical set-backs, coupled with those which have arisen with the first round stations, have made responsible engineers ponder a little more deeply on the paradox that 'obsolescent' though the commercial magnox reactor may be, nobody has yet operated one. From this stems the CEGB's decision to wait for operating experience with the Windscale AGR before building a commercial project, and from the narrowing of the cost gap between magnox and advanced gas cooled reactors stems a realization that the gap might be closed altogether. The CEGB has therefore decided, logically enough, on an intensified drive to get the utmost out of the magnox reactor system and thinks that the way to do this is to keep the design teams in the Consortia with their noses down to detailed tendering: to prepare a complete tender ties up a design organization for a year, and one station a year is the programme.

For the CEGB, which after all is in business to produce electric power, this attitude makes sense, but in the context of the broad advance of atomic energy in the UK it has one or two unfortunate aspects. The CEGB refuses to establish an official 'rota' for its contracts, preferring instead the delicate, ambiguous, but workable gentleman's agreement whereby each Group gets a contract roughly in turn, *provided* its design is up to scratch. But it seems a pity that no other way can be found of ensuring that the Groups maintain their maximum effort. Industry may be compensated for unsuccessful tenders, but this is merely a matter of book-keeping: it does not redeem the wasted effort. Is it certain that designs would not advance just as rapidly if, for example, the civil side of the tenders were not so detailed? It is a sobering thought that with so many technological problems requiring urgent investigation, hundreds of thousands of pounds a year are being spent in the United Kingdom in preparing abortive bills of quantity.

## A material problem

THE SUCCESSFUL EXPLOITATION of nuclear energy depends to a great extent on the ability of our engineers and physicists to develop new materials and extend the range of well tried ones to new and more exacting requirements. The problems, especially those connected with neutron economy and radiation hazard, together with the marginal economics, makes the search exciting and stimulating. Factors militating against successful development might simply be due to bad organization or lack of communication. This month, for example, comes the news that the first loading of the AGR will be only 20% beryllium canned; as recently as last May the AEA was talking in terms of 80% beryllium. One has to ask if this is an example of technological setback, production difficulties, or possible failure to take adequate note and advantage of advances made in other countries?

The present state of knowledge of materials used and their potential use in the nuclear industry is reviewed in this issue. It is a truism that advances can only be expected if they are backed by adequate experimental facilities; it is a fact, however, that none of the UK groups have irradiation facilities of their own. This lack, for instance, has been particularly felt by one firm in respect of the development of protective coatings for graphite used at high temperatures. In this case, however, it was found possible to devise test experiments without the use of full-scale irradiation facilities. Nevertheless, there are bounds to such ingenuity.

Some of the difficulties in this direction will be partially alleviated with the commissioning of Berkeley and Bradwell in the coming year. These two stations will in fact provide the CEGB with what amounts to two irradiation laboratories. The use of the Trawsfynydd pressure vessel to test electric furnace steel is another example and emphasizes the long-term nature of some of the problems. The behaviour of some materials will not be adequately known until they have been used in reactors for some time and this is not only true of the fuels, cladding, and coolants etc. for advanced systems. The behaviour of metallic uranium and magnox will only be adequately tested when the civil stations are running successfully, for some doubts have already been thrown on the adequacy of the fuel elements for these reactors. This is not entirely a materials problem but serves to show that design is more closely related to materials limitations than in many other fields.

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# WORLDVIEW

the month in atomic energy

## EUROPE

### Consortia ask CEGB for compensation

*London* In a new drive to reduce capital costs of magnox power stations to the minimum, the Central Electricity Board has asked each of the consortia to submit fully detailed tenders for future power stations, starting with Oldbury. This will end the practice previously followed by some groups of either missing out altogether on some projects or submitting a 'token' tender without full details on, for example, the civil engineering side. The groups have replied with a formal request for compensation and the whole matter is being negotiated.

Payment of compensation has arisen because the groups' research and development departments will have to spend most of their time on tendering and also because of the high cost of detailed tenders. A CEGB spokesman told *Nuclear Power*: 'This matter has been brought up by the consortia and is under consideration'. No sum has yet been fixed though £100,000 has been mentioned.

Meanwhile, it is reported that difficulties over the Advanced gas-cooled reactor could lead to the ninth CEGB station being magnox (Oldbury is the seventh station). The CEGB's rethinking on tenders and magnox stations is thought to be linked with this. One problem with the AGR is the canning material for fuel elements. The original concept envisaged beryllium canning. However, during the past year, the Atomic Energy Authority announced that some fuel elements in the first loading would be stainless steel —a heavier absorber of neutrons than beryllium, and a material having low thermal conductivity. In May this year, an 80% proportion of beryllium canned elements was given by the AEA for the first AGR loading. But in a recent statement to *Nuclear Power*, the proportion of beryllium canned elements for the first loading was given as 20%.

### Kahl BWR reactor goes critical

*Frankfurt* The first West German nuclear power station to come into operation is the 15 MW Kahl plant which went critical on November 13. Initially, the reactor will be tested at power levels up to 1 MW. It will then be operated at about 50% of capacity for three months during which a series of tests will be carried out. The rest of the fuel will then be loaded and the reactor brought up to its full capacity.

General Electric of the United States designed and provided the single-cycle boiling water reactor for the plant. Its fuel consists of 6·6 tons of slightly enriched (2·6%) uranium dioxide contained in 88 fuel element assemblies. These, plus 12 spare fuel element assemblies, were built by GE at its California plant. Main contractors for the Kahl station are Allgemeine Elektrizitäts-Gesellschaft (AEG) and Hochtief AG. Capital cost of the station is put at 35 million D-marks and it will be owned (80%) by Rheinisch-Westfälisches Elektrizitätswerk (RWE) and (20%) by Bayernwerk, two large West German utility companies.

### HTGC shows promise for marine propulsion

*London* Studies into nuclear power for ships by the British Shipbuilding Research Association team at Winfrith are promising, according to Sir James Milne, chairman of the council of the Association in his summary of the body's annual statement. Members of the Association's research team, also stationed at Risley, have been looking into the possibilities of the high temperature gas-cooled, graphite moderated reactor.

'It appears probable that the AEA will apply more effort to consideration of this type of reactor,' said Sir James.

• **Belgium** Under a recently signed nuclear co-operation agreement, nuclear products will be shipped to Mexico.

• **GATT** Negotiations on reciprocal tariff reductions applying, amongst others, to reactors and components, are expected to begin in Geneva early in 1961.

• **OEEC** The Convention on Third Party Liability in the field of nuclear energy has been signed by 16 countries.

### East German station proceeds

*Berlin* Work is expected to be completed in 1962 on the German People's Republic's first nuclear power station, according to a report from the Scientific and Technical Bureau for Reactor Construction in East Berlin to *Nuclear Power*.

This states that the station at Neuglobsow (Rheinsberg) will have an output of 70 MWE and will use $UO_2$ enriched up to 1·5% in pellets canned in zirconium with light water as coolant.

**BERKELEY TURBINES** Delivery of the first fuel elements for Bradwell and Berkeley nuclear power stations has begun. The stations are near completion and the turbine hall at Berkeley (below) is practically finished

WORLDVIEW

• **Northern Ireland** The Government are still looking for a coastal site for a nuclear power station as the Lough Neagh site has been ruled out for health and safety reasons.

## Isotopes from power stations

*London* A Bill to allow radioisotopes to be produced at the Central Electricity Generating Board's nuclear power stations has received its first formal reading. Called the British Electricity (Amendment) Bill, it seeks to amend the 1957 Electricity Act. Irradiation of cobalt to make Cobalt-60 is the most likely method that will be used. Additional capital outlay involved under the Bill is not expected to be more than £250,000.

**HERO REACTOR** Sections of the pressure vessel for the Hero reactor are now on site. This Hot Experimental Reactor, Zero Energy, is being built at Windscale

## French growth slows

*Paris* A period of consolidation is ahead for the French nuclear industry and future growth will be slower than in the past, says the Commissariat à l'Energie Atomique's annual report.

Reactor systems to be investigated in the future will be: natural uranium fuelled and moderated by heavy water; plutonium breeders and marine reactors using enriched fuel. In addition, the report says that to meet military purposes, the building of uranium processing plants previously studied, will start this year and will be completed in the period 1964–66. First results of comparative studies of the heat transfer properties of British type polygonal fuel element cans and French chevron type cans has shown a slight superiority in favour of the latter, the report adds.

It will be necessary, the report says, to wait until perhaps after 1970 before nuclear power will become competitive in France. This was partly because of the influx of natural gas from the Sahara and the consequent need to make another comparative cost study. Because of this, research had to be undertaken to enable France to take full advantage of the future large-scale use of nuclear energy.

## First UK University reactor licence

*London* Following the Minister of Power's approval of a licence to Queen Mary College, University of London, to install a research reactor, Liverpool and Manchester universities have expressed interest in the Jason Mark III reactor to be supplied to the college.

The Jason Mark III, likely to be the first university reactor to be installed in London, is made by Hawker Siddeley Nuclear Power Company. It has been designed to meet the special requirements of the Queen Mary College Department of Nuclear Engineering for a reactor to act as a source of neutrons to drive fuel element lattice experiments and is capable of driving three such experiments at the same time.

The site licence is the first granted by the Minister of Power for erecting a low-powered—10 kW—reactor in a built-up area. Mr. Richard Wood, the Minister, said the Nuclear Safety Advisory Committee had advised him that so long as the site, housing and design and operation of the reactors fully satisfied certain basic conditions, they could be safely permitted in built-up areas.

In an explanatory statement, the Ministry of Power say factors affecting safety must be considered for each individual project. As far as siting is concerned, it is not suggested that approval be given to all proposals; the advice is that a proposal should not be ruled out merely because it is sited in an urban area.

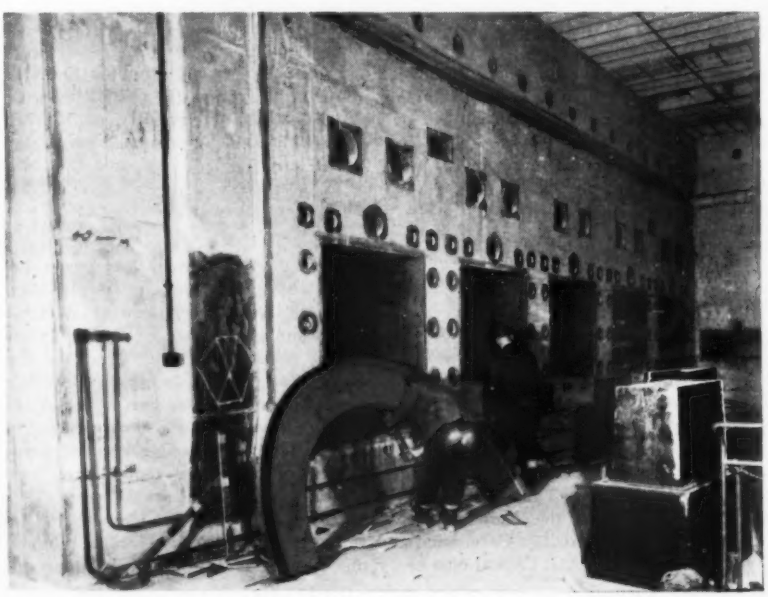
## German ship tenders invited

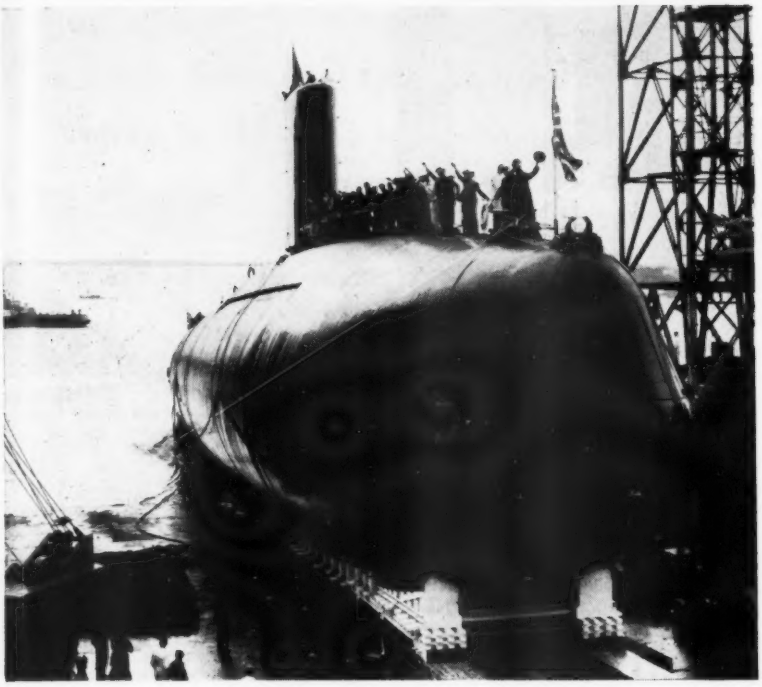
*Bonn* Tenders for the construction of W. Germany's first nuclear ship have been invited by Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt of Hamburg. This company consists of industrial, scientific and Land Government representatives. Eleven shipbuilding concerns are competing for the tender which is for an experimental vessel.

The choice of vessel is left to the builders—tanker, ore carrier or passenger ship. The power has been fixed at 10,000 shp and the Hamburg company is thinking along the lines of a 22,000 tons unit, 177 meters long. A major requirement is that the reactor compartment and link up must be so designed that the reactor will be easily removed and replaced.

At present, it is planned to test a reactor in the vessel and, on completion of the experimental work, to replace it by another type. The Hamburg company, together with Interatom, is designing an organic moderated reactor and recently received a further credit of 3,280,000 D-marks from the Minister of Atomic Affairs for financing current design study work. This brings the total grant from the government to meet costs incurred in developing and building this reactor by Interatom, to 5,500,000 D-marks. It is not yet known which type of reactor will be first installed in the proposed ship.

**HOT CAVES** Construction work is well advanced on one of the five bays off the main corridor of the hot caves being built in the No. 2 Windscale Pile blowerhouse





**'DREADNOUGHT' LAUNCHED** Britain's first nuclear-powered submarine 'Dreadnought' glides down the slipway after being launched at Barrow-in-Furness by Her Majesty The Queen late in October

• **United Kingdom** Because of a minor fire at Imperial Chemical Industries' beryllium plant at Witton, full-scale production has been suspended while modifications are being carried out.

• **Bulgaria** Construction of the IRT-1000 research reactor at the Institute of Physics is nearly complete.

• **Netherlands** Reactor Centrum Nederland, whose Jason research reactor went critical recently, has now put the reactor into operation.

• **IAEA** More than 175 scientists took part in the symposium on Chemical Effects of Nuclear Transformations held in Prague recently.

## Oldbury station approved

*London* Despite the long delay (18 months) in obtaining consent from the Minister of Power to build the 550 MW Oldbury nuclear power station, the Central Electricity Generating Board say completion in 1966 will still be possible.

The contract for preliminary works will be let soon and work will start almost immediately. Tenders for the station, the seventh nuclear power station for which the CEGB has received consent, will probably be invited early next year.

The Oldbury site covers 180 acres, sufficient to permit extension, if required. Advantage will be taken of a rock shelf in the River Severn to create an artificial 350 acre tidal reservoir to impound water at high tide to use for cooling purposes. Application for consent was made in April last year and a public inquiry held a year later. The site is by the Severn Estuary, 4½ miles from the Berkeley station.

## Credits for French industry

*Paris* Credits totalling 2175 million new francs are to go to the French nuclear industry for development work from the Government. Of this total, 935 million francs are for military purposes.

Announcing this, M. Pierre Guillaumat, Minister-Delegate at the Premier's Office for Atomic Energy, said work under way included an expansion of ore processsing facilities to give uranium production of 1300 tons by 1962. Design studies in hand included one on a marine reactor for submarines or for merchant vessels.

# OVERSEAS

## US to build molten salt reactor

*Oak Ridge* A molten salt type fluid fuel reactor experiment to investigate advanced reactor concepts having potential advantages for electrical power production is to be built at the National Laboratory here.

The reactor, the MSRE, is being designed as a 10 MWt reactor though routine operation will be at about 5 MW. No electrical power will be produced. Instead, the heat will be dissipated to the atmosphere through a secondary heat exchanger. Operation is scheduled for spring, 1963.

Molten salt fuels (fused fluoride salts containing uranium and thorium) were originally designed for use in compact, high temperature, high power density, reactors necessary for nuclear aircraft propulsion. The present programme will investigate the possibility for civilian power purposes. It is said to offer potential economic advantages of excellent steam conditions and high efficiency through operation at very high temperatures. As the fuel is in solution, continuous removal of fission poisons is possible.

Early in 1954, a reactor of this type known as the Aircraft Reactor Experiment was operated for a short time at Oak Ridge but later was dismantled. In mid-1959, the AEC announced it was 're-orientating' its fluid fuel programme.

• **United States** Nine reactor safety fuses have been built by Atomics International for the General Dynamics Maritime gas-cooled Reactor Critical Experiment.

• **Formosa** Michigan University is to help the Tsing Hua Institute of Nuclear Science set up and operate its first research reactor.

• **India** 'Apsara', India's first research reactor, is working again after a close-down for maintenance after four years' operation.

## Urals plant nears completion

*Moscow* Construction work has been completed on the Pishchma River dam which will provide cooling water for the Byeloyarsk nuclear power station in the Urals. Work on the turbine hall for the 400 MW station has also been completed.

WORLDVIEW

## Fuji Electric invited to tender for Indian station

*Tokyo* The Indian Atomic Energy Commission has formally invited the Fuji Electric Company to tender for the construction of the 300 MW Tarapur nuclear power station, the Japanese company has stated.

Fuji Electric is a member of the 25 company First Atomic Power industry Group (FAPIG) which is working as the sub-contractor for the Tokai-Mura station being built by the GEC. The Group have said they will co-operate with the GEC over building the Indian station, if the contract were secured. (See *Worldview*, October, p 72).

## Canadian OMR gets approval

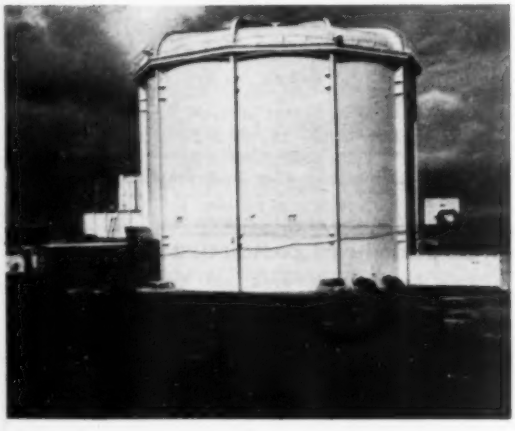
*Ottawa* Atomic Energy of Canada Ltd has approved a programme to design an organic-cooled reactor. Expenditures of about $100,000 a month will be made on the study during the next six months in addition to a previous outlay of $600,000 for a design study of organic-cooled plants.

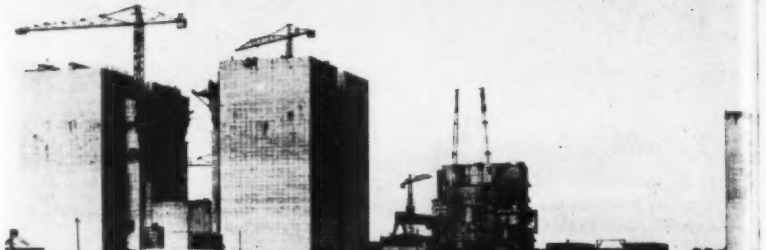
Atomic Energy of Canada hope that the study, if successful, will allow it to recommend such a reactor for the new Whiteshell Nuclear Research Establishment being built near Winnipeg.

## Brazil's second research reactor

*Rio de Janeiro* A Triga research and training reactor at the Engineering School of the University of Minas Gerais, Belo Horizonte, has gone critical. It is the first Triga to operate in South America and together with a research reactor installed at Sao Paulo University, will train Brazilian technicians for what is hoped to be the start of an atomic power industry in the country within five years.

**AUSTRALIA'S HIFAR** Part of the auxiliary plant-room and offices of the Australian AEC's High Flux Australian Reactor (Hifar) is pictured below with one of the eight cooling towers in the foreground





**FRENCH STATIONS AT CHINON** The two nuclear power stations being built by Electricité de France (EDF) along the Loire River are progressing smoothly. At left are the two heat exchangers for EDF-2 and in the background are EDF-1 buildings with a water tower on the extreme right

*(UP photo)*

## Agreement on McKinney report

*Washington* Agreement with the McKinney recommendations for closer North American-Western European nuclear co-operation has been voiced by Senator Clinton Anderson, chairman of the Joint Committee on Atomic Energy. He was commenting on points in the report 'Review of the International Atomic Policies and Programmes of the United States'.

Senator Anderson stated that it was his feeling that the report's major findings of fact would stand. It would, he was certain, be given thorough consideration in the next session of Congress. He agreed with the recommendations that there should be mutual agreement at policy-making levels among friendly nations of North America and Western Europe and that there should be close and frequent working relationships between the countries concerned.

He added that perhaps the Review's greatest impact outside the field of atomic energy as such would be in the broad area of East-West technical and cultural exchanges (see *Worldview*, September, p. 89).

*The Review's findings, conclusions and recommendations are contained in a brief 96-page report, supported by 2000 pages of documentation in four background volumes. Volume 1 may be obtained from the Joint Committee on Atomic Energy, Room F-88, the Captitol, Washington 25, DC. Copies of Volumes 2–5 may be purchased from the Superintendent of Documents, Government Printing Office, Washington 25.*

• **Brazil** Two British engineers, J. Woodfield and M. Ratcliffe, were killed in a helicopter crash near Rio de Janeiro. The two men were employed by Kennedy & Donkin, London, who are helping to prepare specifications for the Mambucaba nuclear power station.

• **Australia** The first of four nuclear power stations planned for Antarctica should be operating next year, Rear-Admiral H. A. Karno of the US Navy said in Melbourne recently.

• **Iraq** The Economic Planning Board has authorized the signing of contracts for building a 2 MW research reactor and an isotope production facility. These will be provided under the Iraq-USSR agreement.

• **Pakistan** An institute of nuclear sciences and technology is to be set up at the new capital, Islamabad.

• **Venezuela** Surveys of mineral deposits in Andean regions have resulted in some uranium deposits being found.

## Aircraft test reactor being planned by Pratt & Whitney

*East Hanford, Conn.* 'Significant studies' in the development of an indirect-cycle system for a nuclear-powered manned aircraft are being made by Pratt & Whitney Aircraft division of United Aircraft Corporation. According to Colonel William A. Tesch, chief of the Aircrafts Project Branch of the Aircraft Nuclear Propulsion Office, research has progressed to the point where present Pratt & Whitney plans include the fabrication of an experimental ground test reactor to prove basic materials and compounds. Colonel Tesch was writing in the current issue of *Air University Weekly*.

In the indirect cycle system, a liquid-metal coolant carries nuclear heat from the reactor to a radiator in a turbo-jet engine where the heat is exchanged to the air to produce thrust.

• **Malaya** Plans for installing a research reactor are being considered by the University of Malaya's Faculty of Science.

# Grenoble Electrostatics Conference

THE GRENOBLE International Colloquium, said to be the first international conference devoted entirely to the science of electrostatics, covered the generation of electrical power by electrostatic means and the applications of these machines. It was held from September 24-October 1 under the auspices of the Centre National de la Recherche Scientifique and, with the presence of Professor N. J. Felici, holder of the chair of Electrostatics at Grenoble University, proved a natural meeting place for the 120 physicists and engineers who attended.

Appropriately, the lectures were inaugurated by a talk by Professor Felici on the types of electrostatic generator and his hopes for the next generation of electrostatic machines. This, in conjunction with a talk by Professor John Trump, Massachusetts Institute of Technology, indicated in broad outline the scope of present possibilities and the problems of the future. There are two types of electrostatic generator in current use: the Van de Graaff belt type machine and the Felici insulating transporter cylindrical machine. Briefly, for high voltages and very low currents, the Van de Graaff is better and for low voltages (below one million volts) and higher currents (up to 50 mA's) the Felici machines are better. For long term continuous running, the cylinder machine is more reliable but in its present state of development it cannot provide the very high voltages or current that may be required.

Professor Trump discussed a further type of electrostatic generator, the disk machine. This is not a new development and on show at the Colloquium was a very early disc type generator built in the late 1940's at Grenoble. This type of design has the greatest development possibilities.

Several papers were presented which discussed the application of this type of electrostatic generator for ion propulsion. Considerable research is being carried out both in France and the U.S.A. on electrostatic machines for this purpose. The design of a generator delivering 1250 kW at 200 kV is being studied at HVEC in Massachusetts. Parallel studies are proceeding in France. The future development of the cylinder machine is being studied to increase the currents available and other dielectrics, including various liquids, are being studied. Questioning elicited visualised requirements of 100 kV at 100 mA's to 1 Mev at 1 amp, but no concrete suggestions as to how this might be achieved were agreed.

Of particular interest on the nuclear side were the neutron generators capable of delivering fluxes of neutrons up to $10^{11}$ neutrons per second. Continuous development aimed at greater fluxes with smaller machines is being carried out.

To sum up, the position of the electrostatic generators at the present time is not easy. Both the French and American experts expressed faith that the present machines are the first in a field capable of great development. Discussion gave glimpses of actual development models in course of construction at the present time. Whether certain fundamental difficulties will obstruct this advance or whether new techniques will emerge remains to be seen. Whatever happens, great resources of money and labour will have to be made available.

The remainder of the lectures dealt with the applications of electrostatic machines. Two very interesting lectures were given by Dr Allen, UKAEA, Harwell, and Mr Julian, UKAEA, Aldermaston. These two lectures described the remarkable achievements of the staff of the AEA in constructing two 12 Mev Tandem accelerators which have now been in operation for the last year. The many problems which they encountered and overcame were discussed and a resumé of the experimental work carried out, both in the design of the machines and their subsequent usage, was given.

Future applications in the nuclear field would appear to lie with neutron sources of higher fluxes than at present available. If fluxes of the order of $10^{12}$-$10^{14}$ neutrons per second could be produced economically, there would be a demand from those at present forced to use reactors for activation experiments. There is some argument as to what an economic figure might be but there is a real hope that an accelerator working at, say, 1 MeV, 4 mA's of ions in the beam of a beryllium target could produce a flux of $10^{12}$ neutrons per second. From preliminary inspection, it was severally agreed that the price of such a machine might be very attractive *vis-a-vis* a small reactor. A 1 MeV accelerator and a high current ion source of this type was shown to the members of the Colloquium.

# W. German plans for 1961

*Bonn* Special expenditure amounting to 21,150,000 D-marks (£1·8 million approx.) has been provided for help in 1961 in planning and building experimental/prototype reactors under the 1961 draft budget presented to the Bundestag by the Federal Minister for Nuclear Energy. Of the total earmarked for 1961, 9,650,000 D-marks have already been granted.

From 1956–60, the West German Atomics Ministry made available 196,025,000 D-marks for promotion and development of nuclear technology and research of which 43 million D-marks were for the planning and construction of experimental reactors.

The money allocated for 1961 can be used as advances, loans or contributions and in presenting the 1961 budget for 186 million D-marks, the Ministry say that as design and construction are expensive and, for the time being, uneconomic, the Government should partly finance design and construction work.

## Reactor Project Costs

| *Reactor type* | *Design period* | *Total costs* (1000 DM) | *Govt. grant* (1000 DM) |
|---|---|---|---|
| Heavy water pressure tube | 1959–62 | 14,560 | 1200 |
| Gas-cooled Natural uranium | 1959–61 | 9850 | 800 |
| BWR with nuclear conventional superheat | 1959–61 | 9600 | 800 |
| PROPULSION REACTORS | | | |
| OMR | 1959–61 | 7500 | 1000 |
| BWR | 1960–61 (1st stage) | 3000 | 825 |
| PWR | 1960–61 | 3000 | 525 |
| CONSTRUCTION OF STATIONARY POWER REACTORS | *construction period* | | |
| 15 MWe high temp. | 1959–63 | 40,000 | 4500 |
| 50 MWe multi-purpose | undecided | 100,000 | 5000 |

SMALL AND MEDIUM REACTOR DEVELOPMENT—1960–62

1. High temperature reactor with homogeneous fuel elements in impervious graphite sheaths linked with a gas-turbine—5 to 20 MWe.
2. Advanced gas-cooled reactor with slightly enriched uranium fuel—35 MWe.
3. Organic moderated and cooled reactor—25 to 35 MWe.
4. BWR with nuclear superheat—25 MWe.
5. Mobile small power plant using a PWR—2 to 10 MWe.

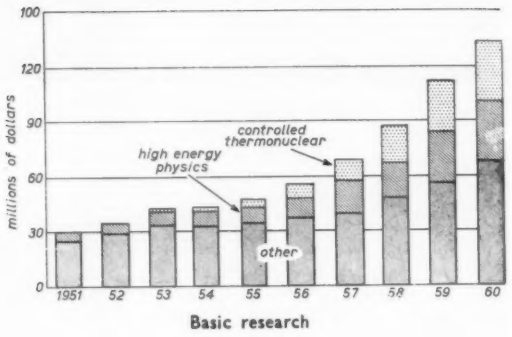
Cost of planning and development and experimental work for projects 1–4 is put at 20 million D-marks each. After preparatory work, prototype reactors will be built if these projects appear worth developing. Building costs are put at 35 million D-marks each with Federal contributions foreseen for 1961 as 6 million D-marks.

OTHER DEVELOPMENTS

Federal contribution 500,000 DM.

# AEC financial report for 1960

## Expenditure increases steadily



Basic research

AN INCREASE in revenue from sales and materials and services for the 1960 financial year of $6 million (£2·25 million approx.), from $9M in 1959 to $15M in 1960, is shown in the US Atomic Energy Commission's financial report for the year ending June 30, 1960. The main increase came from source and special nuclear materials where revenue increased by nearly $3 million.

The net cost of operations in 1960 rose by just over 5% compared with the 1959 figure. This is less than the 1959 increase over 1958 which was 9% and reflects a steady increase of expenditure on all items with the exception of naval and aircraft propulsion reactors.

### Industrial power

In its Power Demonstration Reactor Programme, the AEC co-operates with ten private and public organizations. Its plan bore fruit during the year when the Yankee Atomic Electric Company's 136 MWe pressurized water reactor became critical on August 19, 1960, becoming the first nuclear power plant under the programme to achieve criticality. One of the reactors scheduled to go critical in the near future is that being built by the Power Reactor Development Company of Michigan. Its Enrico Fermi 94 MWe developmental fast neutron power breeder was scheduled for completion this month (late December). However, the pending appeal to the Supreme Court over the decision against the AEC over the granting of a licence to build the plant may delay matters.

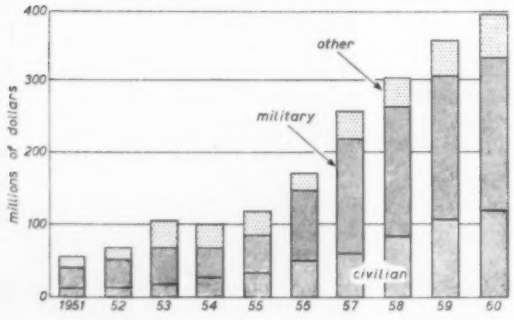
The Elk River (Rural Co-operative Power Association) plant is also due to go critical soon. This is a 22 MWe closed cycle boiling water reactor with superheater.

The report further notes that the US Government has invested some $22,210·1 million in the nuclear programme in the period June 1940 to June 1960. This figure includes appropriations for the war effort (including the Manhattan Engineer District Project) and for the Commission in the post-war years.

#### MAIN POINTS

1. Procurement and production of nuclear materials provided the major part of costs. In 1960 these cost $1·4 thousand million or 55% of total operating costs.
2. Development of power and propulsion and other reactor research cost $399 million (£142 million approx.) against 1959 costs of $356M (£127M).
3. Value of materials leased domestically and overseas totalled $99M (£35M) against $72M (£26M) in 1959.
4. Of the $133M (£47M) spent on physical research, $32M (£12M) was for controlled thermonuclear research and the same amount for high energy physics.
5. Costs of research into effects of radiation in the environment on living organisms were $49M (£18M) compared with $43M (£16M) in 1959.
6. Total cost of production of special nuclear materials to meet the weapons production schedule, other military needs and peaceful requirements increased in 1960 to $731M (£260M), or 2·5% increase over 1959.

*(Note: The UKAEA estimates for 1960-61 provide for a net expenditure of £93,293,000)*



Reactor development expenditure in 1960 was four times that spent in 1954 and nine times the 1951 total

### Fuel costs fall again

While the total quantity of uranium concentrates purchased in 1960 increased by 4% over 1959, foreign purchases remained at the 1959 level. In addition, the average cost of U-308 fell by 15 cents to $10·19 per lb. Prices paid to suppliers for U-308 produced in privately owned domestic mills averaged $8·78/lb in 1960 against $9·18 in 1959.

The total cost of production of special nuclear materials including uranium-235, plutonium and other materials to meet the weapons production schedule, other military needs and the requirements for peaceful uses of atomic energy increased in 1960 to $731M compared with $713M in 1959, an increase of 2·5%. Although the total cost increased, the unit cost of production continued to decrease in 1960.

### Basic research

The major areas under study included basic investigations of the laws of nature, including nuclear interactions at high energies, the effects of irradiations on the behaviour and properties of materials and research effort to harness thermonuclear energy. There was increasing emphasis on the latter. Costs of high energy physics increased by 17% over 1959 with the major effort centring around attempts to learn as much as possible about the fundamental properties of nuclear matter through research with high energy particle accelerators.

### Material and services sales

Sales of source and special nuclear materials together with heavy water sales brought in more income in 1960 than the total from all items in 1959.

Radioisotope sales amounted to $2·4M against $2·5M in 1959 while foreign sales decreased to $391,000, six per cent less than in 1959. The dollar volume of sales has levelled off due to substantial reductions in recent years in the most popular radioisotopes such as Cobalt-60, Iodine-131 and Carbon-14.

*When selecting a material, the nuclear engineer has to consider not only its 'conventional' properties but also a set of parameters such as neutron absorption, atomic weight and behaviour under irradiation which puts many well-known materials in an entirely different light and stimulates the development of new forms. In this survey the authors give a brief picture of each material as it appears to a reactor designer and endeavour to answer the question 'where do we go from here?'.*

# MATERIALS IN ATOMIC ENERGY

*General Editor Prof. J. G. BALL, B.Sc., FIM, Imperial College*

## FUELS

### URANIUM

UNALLOYED metallic uranium still has potentialities in power-producing reactors and consequently a great deal of research has been, and is being, directed towards examining and understanding its properties. For example, due to out-of-pile experiments, the effects of thermal cycling both in the alpha phase region and through the alpha-beta transformation are now understood and to some degree are predictable by calculation.

The behaviour of the metal in a reactor, particularly over 400°C, is not so well understood neither is it so readily predictable. The swelling at burnups of 0·5% can vary between 10 and 100 vol-%. Many factors could contribute to this. While the gross shape changes, observed in specimens due to the growth phenomenon, have been removed by grain refinement, growth still lowers the creep strength of the metal and may cause local embrittlement by means of internal stress; in these ways the growth phenomenon contributes to swelling. There is some evidence that the worst swellings are obtained in the specimens subjected to most thermal cycling. Details of microstructure may exercise a controlling influence on swelling in ways which are not yet fully understood.

Studies of the effect of alloying additions on the behaviour of uranium are going ahead in all countries interested in nuclear power. The main aim in alloying is the elimination, or a reduction in the amount, of the undesirable orthorhombic alpha phase. Its elimination from the structure requires relatively large amounts of alloying element, for example, about 10 wt-% of molybdenum (zirconium or niobium have the same effect as molybdenum), which in turn requires expensive enrichment. However, metallurgically the improvement is considerable; in the USA the 10 wt-% Mo alloy has been irradiated to 0·8% burnup at 575°C and only decreased in density by 4%. At lower alloying concentrations, it seems that some of the benefits of alloying can be combined with better neutron economy. An example, used in the US EBWR, is the 5% Zr, 1·5% Nb alloy. This, when quenched from the gamma phase, shows extraordinarily good corrosion resistance in water but not particularly good irradiation stability. However, when slowly cooled, the irradiation properties are markedly improved and it is corroded by water. This shows that the microstructure of alloys are of first importance in determining properties. In the next decade, the study of dilute uranium alloys will proceed with the aim of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**FUELS**

URANIUM, PLUTONIUM, THORIUM *J. J. Stobo, C. A. Parsons & Co Ltd*

**CLADDING**

ALUMINIUM, MOLYBDENUM, ZIRCONIUM *A. Carter, ICI Metals Division*

MAGNESIUM *G. M. Michie, C. A. Parsons & Co Ltd*

BERYLLIUM *L. R. Williams, AEA, Springfields*

STAINLESS STEEL *P. C. L. Pfeil, AERE*

NIOBIUM, VANADIUM *A. E. Williams, AEA, Springfields*

**MODERATORS and COOLANTS**

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WATER *N. Battle and C. C. Horton, Rolls-Royce Ltd*

ORGANICS *J. Lamborn, Hawker Siddeley Nuclear Power Co. Ltd*

CARBON DIOXIDE, HELIUM, NITROGEN *P. C. Davidge, AEA, Risley*

HYDROGEN *D. Bradley, AERE*

BERYLLIA *J. Williams, AERE*

LIQUID METALS *K. Hargreaves, AEA, DFR*

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RARE EARTHS *H. L. Parker, Rolls-Royce Ltd*

**SHIELDING MATERIALS**

CONCRETE and other materials *A. Jackson and E. W. Sidebotham, AEA, Risley*

**COMPONENTS**

CONCRETE *S. Gill, GEC*

FERRITIC STEELS *D. R. Harries, AERE*

SEMI-CONDUCTORS *P. H. Stephens, Texas Instruments Ltd*

striking a balance between satisfactory irradiation stability and neutron economy.

Uranium dioxide is probably the best-proved fuel of all. It is certain that it can give 10,000 MWd/tonne burnup, and quite possible that it will give considerably more. Its compatibility with oxidizing coolants such as water and $CO_2$ is excellent and it presents few compatibility problems in contact with canning metals. Extensive studies of fabrication methods and reactor performance have been carried out in UK, Canada and the USA, and the major obstacles to the widespread use of $UO_2$ have been removed. A few interesting problems remain: it has been shown that specimens of the same composition, density and irradiation released quite different amounts of fission gases, apparently because they had been prepared by different fabrication methods. If this could be understood, the fission gas retention in $UO_2$ might be still further improved and longer burnups might be possible.

Uranium carbide has 30% more uranium per unit value than $UO_2$ and its thermal conductivity is higher by a factor 6–8 at 600°C. These facts have lead to an intensive study of fabrication methods and properties of the carbide in the last two years. The favoured method in the USA at present is arc-melting and results of irradiations on arc-melted material are now available. After 13,750 MWd/tonne at 700°C the specimens show only a few microcracks with negligible density changes; the fission gas release is about 0·1% of the amount produced. This works out at exactly the amount expected by recoil from surfaces.

Since UC reacts with oxidizing coolants, its application will probably be in the sodium or organic cooled types of reactor. The main development effort will probably be aimed at finding simple and economical ways of fabrication. It may be that irradiation experience will demonstrate that very high density material is not required. Cheaper sintering techniques might then be developed.

The other main category of solid uranium fuel material is the dispersion. Here the desirable irradiation stability of $UO_2$ or UC can be combined with the high strength and conductivity of a metal (cermet) or possibly with graphite as in HTGCR. In these cases, the separation of the fuel particles and dilution by the matrix both worsen neutron economy. But for the highest temperatures, heat fluxes and burnups, these fuels, highly enriched, will be used.

Liquid metal fuels and slurries, e.g. U-Bi, $UO_2$-Na should not be forgotten. Reactors fuelled in this way have many apparent advantages but the corrosion problems are still not solved.

## PLUTONIUM

A METAL with six allotropic modifications between room temperature and its melting point at 640°C obviously cannot be used as a solid fuel in a power reactor. The attention of the metallurgist, therefore, turns to alloying and that of the ceramist to refractory compounds such as the oxide and the carbide.

The plutonium alloy system with the most advanced technology is that with aluminium. At the aluminium-rich compositions, the alloy comprises $PuAl_4$ surrounded by virtually pure aluminium. This material is extremely resistant to corrosion by high temperature water; it is much better in this respect than the aluminium-nickel alloys which have been considered as canning alloys. A most interesting development in the production of these alloys has been made in Canada where it has been shown that the reduction of $PuO_2$ by aluminium in the presence of cryolite gives the alloy directly. Thus the preparation of plutonium metal is avoided and this gives considerable economic advantage.

Plutonium uranium alloys show disappointing irradiation behaviour but when molybdenum is introduced there are improvements. Workers at Argonne report that uranium containing 20% plutonium and 5 to 10% 'fissium' shows very satisfactory irradiation stability. ('Fissium' is the name given to a collection of alloying elements left after pyrometallurgical reprocessing of fuel: it is largely molybdenum and ruthenium.) This is to be the fuel for the Experimental Breeder Reactor EBR II, the sodium cooled fast reactor in the USA.

The Russians report the use of sintered $PuO_2$ as the fuel for their fast reactor BR-5 but give no details of fabrication or fuel performance. The oxide is isomorphous with $UO_2$ and $ThO_2$ and these form continuous series of solid solutions. The $PuO_2$-$UO_2$ series is of obvious interest for breeding reactors and at the 5 to 1 mole ratio of $UO_2$ to $PuO_2$ which seems most attractive for breeding, sintering is fairly easy, and the pellets dissolve in nitric acid much more readily than $PuO_2$. A breeder reactor using this as fuel does not seem far away and no doubt laboratory studies of sintering behaviour and fission gas release will continue.

Another attractive approach to fast reactor fuel containing plutonium is the oxide cermet with a matrix of, say, stainless steel or niobium. High integrity cermets can easily be made at about 20% ceramic phase, which is all the plutonium that is required in a fast reactor fuel and preliminary experiments have shown no compatibility troubles up to 1400°C. The future for these materials, with or without $UO_2$ additions, looks promising.

Little is published about the carbides of plutonium but it is likely that solid solutions of PuC in UC or cermets based on these will be the subjects of considerable future interest.

## THORIUM

THE cross-sections of U-238 and Th-232 are such that the most efficient use of thorium can be made in thermal reactors while the uranium-plutonium cycle is best in fast reactors.

Thorium is face-centred cubic up to its only transformation temperature at 1360°C and hence suffers from none of the disadvantages which uranium derives from its crystal structure and allotropy. Irradiations of Th-10 wt-% U alloys at 650°C to 1% burnup show only 5% volume change. It seems likely that even higher temperatures and burnups will be achieved as these experiments continue. The strength of thorium is considerably less than that of uranium and therefore its use in metallic form involves a design in which the thorium is not required to carry much load. In some applications this may be a restriction and therefore a search of alloying elements which strengthen thorium at reactor temperatures will, when successful, enlarge the use of metallic thorium.

The oxide $ThO_2$ is one of the most thermodynamically stable oxides known and thoria-urania solid solutions are obvious choices for water-cooled reactors. Oxide fuels of this type have been developed in the USA. Mixtures of $ThO_2$ and $U_3O_8$ can be sintered in air to very high densities and pellets canned in zircaloy are to be used in a water-cooled power reactor, the CETR.

For reactors with coolant temperatures of 600°C and upwards, there is considerable interest in thorium. In these contexts it is envisaged as the carbide and is generally mixed with uranium carbide. The fuel elements for the Dragon HTGCR are of this type dispersed in graphite and irradiation trials on these up to 1000°C have given very satisfactory results.

In summary, thorium offers few serious material problems. The extent of its use will be decided by economists and nuclear physicists rather than by metallurgists or ceramists.

J. J. STOBO

# CLADDING

*More research and development is needed before the ideal choice can be made from among this unusual group of metals*

## MAGNESIUM

THE low absorption cross-section of magnesium to thermal neutrons (0·059 barns/atom), its compatibility with uranium metal, its adequate oxidation resistance in carbon dioxide up to about 500°C, its good thermal conductivity (0·38 cal/cm s°C) and its relatively low cost, constitute the principal factors that have contributed to the choice of this metal, suitably alloyed, for cladding the uranium fuel in $CO_2$ cooled, graphite moderated reactors of the Calder Hall type.

For this application, an alloy containing about 0·7% Al and 0·007% Be (Magnox A12) has been developed in the UK; the Russians report the use of an alloy containing 2–4% Be, produced by the co-deposition of magnesium and beryllium from the vapour phase. The French G2 and G3 reactors use fuel elements clad with an alloy containing about 0·6% Zr (ZA), which material, because of its fine grain size, is also receiving considerable attention in this country as a possible replacement for A12.

In addition to the steady creep stresses imposed on fuel element cladding, it is also possible that cyclic stressing occurs due, for instance, to aerodynamic vibration in the gas stream. There is, however, little published work on the high temperature fatigue behaviour of magnesium alloys. The French have shown that the fatigue strength of the inherently fine grained ZA alloy up to 400°C is appreciably higher than that of pure magnesium, whereas work in UKAEA laboratories on the A12 alloy suggests that the improvement cannot be directly attributed to the fine grain size of the ZA alloy.

Work on the effects of neutron irradiation on the mechanical properties of magnesium alloys has been mainly restricted to post irradiation testing. The changes observed are not regarded as significant, it being assumed that the irradiation hardening annealed out at the temperature of irradiation (about 50°C). Whether the properties are likely to be impaired during deformation under irradiation is not, however, so clear but remarkably high ductilities have been claimed by the Russians for their 2% and 4% beryllium-containing alloys, as exhibited during actual irradiation of fuel elements at about 440°C.

Tests on magnesium alloys have revealed that spontaneous ignition does not occur in dry carbon dioxide until well above the melting point (m.p. about 650°C); the presence of 800 p.p.m. moisture however reduces the ignition temperatures to much nearer the melting point. The ignition temperatures in air are significantly lower, especially in the presence of moisture and it is under these conditions that the beryllium containing alloys are claimed to offer advantages.

In addition to their application as cladding materials, magnesium alloys may be used as fuel element support members; in these circumstances, the creep strength of the cladding alloy may not suffice, particularly at the higher operating temperatures. This is generally met by alloying with 0·75–1·5% Mn but since this element involves a nuclear penalty, ternary alloys containing only about 0·1% Mn but with 0·2–0·6% Zr are being developed. These have the added advantage of a finer grain size with possibly a better creep ductility at 400–500°C.

The demand for magnesium alloys to meet the high standards required of nuclear fuel element cladding has set a number of production problems. Multi-start spiral cans, originally machined from the solid bar, are now impact extruded and twisted to finished profile, an example of how production technology has advanced to meet the nuclear engineers' requirements.

G. M. MICHIE

## BERYLLIUM

BERYLLIUM is unique in that it has the lowest capture cross-section of all metals and this fact, combined with a melting point of 1280°C, good heat conductivity, and a useful array of properties above 900°C, make it an attractive proposition for both fuel elements and supporting structure. Some limitations of importance are the brittleness of the metal in preferred directions at room temperature, the high initial cost of the metal, and the density of the element in the finely divided condition which increases fabrication costs.

The non-availability of casting processes to give a product satisfactory for direct fabrication has led to the universal adoption of powder metallurgy methods for fabrication. Techniques are now available for the fabrication of a wide variety of components, including rod, tube, extruded sections, and forgings. Machining methods are also available for nearly all conventional shapes. The development of joining techniques has now reached the point where satisfactory methods are available for a wide range of joint designs. The problem of irradiation damage arising from helium formation is well known. However, recent data suggests that at the temperatures of interest for the AGR this phenomena will not impose an unacceptable limit to its application.

The availability of cast metal for direct fabrication could yield both economic and technical advantages and this line of development is being widely studied. Considerable attention is also focussed on improving our understanding of the role played by minor impurities in determining the structure and properties of the metal, particularly the ductility. However, lack of basic data is a handicap and much time and effort needs to be expended in order to establish a good foundation on which a full appreciation of the properties and future possibilities of the metal can be built.

L. R. WILLIAMS

## ZIRCONIUM

ZIRCONIUM is one of the most versatile of the low neutron absorption metals, combining high mechanical strength at room and moderately elevated temperatures, good compatibility with uranium dioxide, and after alloying, good corrosion resistance to water, steam or carbon dioxide up to high temperatures. Use of zirconium alloys for nuclear fuel cladding and structural purposes in pressurized and boiling water reactors is increasing.

Research and development effort on zirconium alloys is aimed at finding a replacement for zircaloy 2 and at developing alloys with higher strength and better corrosion resistance, both for water/steam applications, where the target is a fuel sheathing alloy for operation in steam up to at least 500°C, and for applications in carbon dioxide at temperatures well above 500°C. Alloys being studied for water/steam applications include new alloys in the zircaloy series, zirconium-niobium alloys, and also the zirconium-copper-molybdenum 'ATR' alloy, which, although originally developed for use in carbon dioxide, shows considerable promise for high temperature steam applications. In the gas-cooled field, improved zirconium alloys may well find applications as small structural components in AGR

type power reactors, with carbon dioxide coolant temperatures up to 600–700°C.

It might be possible to develop zirconium alloys suitable for fuel sheathing in gas-cooled reactors with carbon dioxide coolant temperatures up to about 600°C. Such alloys would be cheaper than beryllium, but would have a 10 : 1 disadvantage with respect to macroscopic neutron absorption cross-section, which might prove prohibitive.

A. CARTER

## STAINLESS STEELS

AUSTENITIC stainless steels possess both strength and ductility at room temperature and at elevated temperatures and have resistance to gas coolant such as carbon dioxide and carbon dioxide containing a few percent of carbon monoxide. They are also resistant to sodium and to organic liquids. Present evidence indicates that irradiation to quite large fast neutron doses does not result in unacceptable changes in properties. Established techniques exist for producing thin walled strip and tubing and for making end seals. Problems arise because the high thermal neutron absorption of the main ingredients necessitates thin cans e.g. 0·01 in., which gives a potential integrity problem in that inclusions and flaws produced in commercial material may occupy a significant fraction of the wall thickness. A big contribution to solving this problem is by the use of ton-scale consumable electrode vacuum remelting, a process originally developed for the consolidation of titanium sponge. The integrity problem is accentuated by the somewhat primitive methods of non-destructive inspection at present available. Eddy current inspection will not necessarily reveal cracks as deep as 0·003 in. if the walls show local irregularities of thickness of 0·0002 in. Although the outside surface can be inspected with dye penetrants in tubes of comparatively small bore, access to the inner surface is more difficult.

The corrosion allowance including that for intergranular penetration under stress is necessarily small. Furthermore the steel must not embrittle in service. For carbon dioxide cooled reactors indeed none of the standard steels of AISI types 304, 321, 347, 316 or 310 is ideal at the maximum can temperatures needed for thermodynamically satisfactory coolant temperatures. Steels in which a high chromium content is balanced by a high nickel content appear attractive despite the somewhat higher thermal neutron absorption of nickel compared with iron and chromium. It was on these grounds that 20/25/Nb was selected for the first charge of the Windscale AGR. Such fully austenitic materials are more liable than the 304, 321, and 316 types to weld integrity difficulties. While thin sections are less prone to troubles of a metallurgical origin than thick sections, the standards of integrity required are so high that the problem cannot be lightly dismissed.

For the future thinner cans may be required (0·006 in. perhaps) or temperatures higher than 650°C. Precipitation hardened materials may give the strength needed to meet the more severe conditions but work is needed to determine the extent to which aged properties are retained under irradiation.

P. C. L. PFEIL

## ALUMINIUM

IN the gas-cooled field, there is little incentive to develop improved aluminium alloys for fuel cladding in competition with magnesium alloys. In the water-cooled field, however, where the corrosion resistance of aluminium under power reactor conditions has been found wanting, the higher cost of zirconium alloy fuel sheathing on the one hand, and the high fuel cost associated with the use of stainless steel on the other, has stimulated intensive work on the development of improved aluminium alloys.

One field in which aluminium and its alloys could be used for fuel cladding is the low temperature water-cooled reactor in which the reactor coolant is used for water heating purposes, as in district heating schemes, or the supply of process steam, in addition to electrical generation.

Generally, the corrosion problem becomes serious at about 200°C. Above this temperature, rate of attack is serious, resulting from exfoliation of protective oxide films by hydrogen blisters. The main method of trying to avoid exfoliation has been to add alloying elements of the type which are likely to encourage the conversion of hydrogen ions into gaseous hydrogen at an early stage, and such elements include nickel, iron, copper, cobalt and the platinum group of metals. In addition, some attempt is normally made to increase the corrosion resistance of the alloy matrix, for which purpose silicon, titanium, zirconium and beryllium have been recommended. The problem is, however, difficult, and although alloys with increased corrosion resistance to static pure water have been developed (e.g. the 'Aereal' series of alloys), performance under dynamic water flow is disappointing.

More recently, aluminium in the form of sintered aluminium powder (SAP or APM) has returned to the limelight for sheathing uranium dioxide fuel in the organic liquid moderated and cooled reactor system which is under development in many countries, particularly for marine propulsion. In this field, it is the only low neutron absorption cladding metal being considered, and its competitor is stainless steel. Suggested operating conditions are a maximum fuel element surface temperature of about 450°C, with a coolant outlet temperature of about 360°C. Large increases in organic liquid coolant temperature are unlikely, in view of the more rapid radiolytic decomposition, and SAP should be competitive to stainless steel for a long time. For these SAP applications, the main development effort is being devoted towards methods of end sealing SAP clad fuel elements, and compilation of irradiation experience.

A. CARTER

## NIOBIUM

PURE niobium has excellent resistance to corrosion by liquid metals provided that the oxygen level of the coolant, reduced by hot and cold trapping, is maintained at a level lower than 5 p.p.m.

To manufacture fuel element cans the metal has to be purified from the relatively impure powder form which results from the reduction process. The main impurities which embrittle the metal are oxygen, nitrogen, and carbon. This purification process is integrated with the consolidation route for the massive metal, a powder metallurgy process being at present used in the UK. An alternative method, applied successfully in the USA, is electron beam melting and is now being considered in the UK.

The consolidated metal is currently converted to tubes in the UK by a cupping and drawing technique, carried out at room temperature, and requiring several inter-stage high vacuum anneals at approximately 1200°C. About 70% cold work is permissible between anneals. A possible development once billet metal is available would be production by extrusion or a similar technique, either cold or at elevated temperatures using a suitable cladding.

Niobium may be welded by resistance or argon arc methods. For the latter in particular a vacuum purged chamber is necessary to prevent the pick up of deleterious impurities. Some porosity results in the fusion zone of arc welds, presumably due to the reaction of trace impurities of carbon and oxygen. Normally this porosity does not result in a leak path through the weld.

The thermal conductivity (0·125

cal/cm s °C) is much superior to austentic steels (0·036 cal/cm s °C) and increases with temperature increase.

The tensile properties of unirradiated niobium vary greatly, depending upon the amount of interstitials present and previous history, an increase in the oxygen content from 0·03% to 0·016% increasing the limit of proportionality from 28,200 to 61,200 lb/in². After irradiation, yield strength increases by approximately 15% and the rate of work hardening is reduced greatly, resulting in deformation once started, continuing in the same place until fracture occurs.

Hydrogen absorption by niobium becomes rapid at 350–400°C, embrittlement resulting. This property is used in the recycling process for scrap recovery.

The future of niobium depends on the development of a more oxidation resistant alloy with improved creep resistance, many high temperature structural applications then become possible, whilst use in US reactor systems and electronics industries is predicted to be on a large scale by 1975.

A. E. WILLIAMS

## VANADIUM

VANADIUM is used as the inner tube of the fuel element in the fast reactor at Dounreay, as a safety device in case of reactor fault conditions.

Present information indicates that, apart from this highly specialized use, the future of vanadium as a nuclear metal, or for high temperature use, is not of great promise. Its corrosion properties are not of a high order, and its resistance to oxidation is so low that it is incapable of self protection, even at moderate temperatures—so much so that bar 1 cm dia. is completely converted to oxide in 40 h at 700°C in freely circulating air.

For its use as a canning material in the Dounreay fast reactor, the powder, milled from sponge produced by the Kroll process, is direct resistance sintered in high vacuum, rolled to sheet and cupped and drawn to tube. One of the problems associated with this process is the susceptibility to critical strain grain growth. Unless there is close control of heat treatment, the large grains at the basal radius elongate, producing splits in the drawing direction.

Vanadium is compatible with molten sodium provided that the precautions used for niobium are enforced, but fails preferentially to niobium when in contact with molten uranium. Its neutron capture cross section is 4·5 barns, making it suitable for use in this type of reactor system.

A. E. WILLIAMS

## MOLYBDENUM

MOLYBDENUM and its alloys are being considered for fuel sheathing in advanced sodium-cooled fast reactors in view of their high strength, good corrosion resistance to liquid sodium and potassium, coupled with very good compatibility with uranium metal, even in the liquid state. Particular attention needs to be paid to minimizing the oxygen content of the liquid metal coolant in view of the poor oxidation resistance. Molybdenum is a promising material for use in liquid-fuelled reactors for containing molten uranium-bismuth or plutonium-bismuth fuels, in view of its high corrosion resistance to these liquid metals.

Molybdenum is also used as an alloying addition to uranium metal for fuel rods, for both thermal and fast reactors, in order to obtain higher strengths and better performance under irradiation. It is compatible with uranium dioxide, and incorporation of molybdenum fibres in $UO_2$ fuel pellets to increase thermal conductivity, has been suggested.

A. CARTER

# MODERATORS

*Will graphite-fission product reactions be troublesome? What is the fission neutron age in heavy water? Why are test results on beryllia inconsistent?*

## GRAPHITE

IN the field of ordinary nuclear graphite, the main advances have been in knowledge of the irradiation effects at the operating temperatures of the CEGB reactors. As a result of the Wigner stored energy data now available, graphite sleeving has been eliminated except at Hunterston where a sugar-impregnated sleeve is an integral part of the design of the fuel element. The revised data on dimensional changes has meant that in certain cases parts of the cores have had to be remachined.

A change to beryllium or stainless steel as the canning material for the prototype Advanced Gas Cooled Reactor at Windscale enables coolant outlet temperatures in the region of 500–575°C to be considered, and this gives rise to physical and chemical problems with the graphite moderator. The radiation induced carbon dioxide-graphite reaction would not be negligible over the lifetime of the prototype AGR. Efforts are therefore being made to reduce the reaction by restricting the accessible surface and by introducing gaseous inhibitors.

In the experimental gas-cooled reactor (EGCR) at Oak Ridge, these problems are avoided by the use of helium as coolant. With both the AGR and the EGCR one of the more difficult problems to evaluate is the irradiation shrinkage of the graphite. In the EGCR it is calculated that such shrinkage can lead to bowing of the graphite columns and significant internal stress across a block unless relieved by radiation induced creep.

The design adopted in the various high temperature gas cooled reactors depends chiefly on the method of dealing with fission products. One approach permits their release into the main coolant circuit. Thus, in the Los Alamos Turret Experiment, unclad porous impregnated graphite fuel elements are intended to be used, whilst in the BBC-Krupp reactor fissile and fertile fuel is separately dispersed in graphite balls of low permeability. Some delay in the release of fission products is obtained in the Dragon reactor experiment by enclosing the fuel in a graphite box of controlled permeability to fission products, thereby reducing the load on the trapping circuit and also utilizing some of the fission product heat within the reactor.

Apart from the Turret Experiment the graphite requirements for these reactors are very similar. Initially the emphasis was on obtaining graphite of low permeability, about $10^{-6}$ cm²/s, or a million times lower than ordinary graphite. This has been effected by impregnation of fine grain graphite with carbonized resins. With this primary objective achieved attention is now turning to other possible problems, particularly reactions of graphite with fission products such as caesium.

M. S. T. PRICE, P. A. P. ARRAGON

## WATER

THE thermal neutron constants of $H_2O$ and $D_2O$ are now well established for most practical reactor computational purposes. With a transport mean free path of 2·46 cm and a diffusion area of 10,000 cm², $D_2O$ provides an excellent moderator with almost negligible neutron capture for

those reactors in which neutron economy is of great importance. The absorption of neutrons in $D_2O$ is very sensitive to light water contamination; even at $D_2O$ concentrations of 99·8%, about one-half of the absorption is due to the light water content. In light water, the transport mean free path is about the same (2·74 cm) as that in $D_2O$, but absorption in the hydrogen reduces the diffusion area to 7·46 $cm^2$. It is thus suitable only for reactors in which neutron economy is not an overwhelming consideration. The fast neutron constants (fission neutron age) in both light and heavy water have been comparatively poorly known until recently. Experimental and theoretical work has now established the age in $H_2O$ at 26 $cm^2$ to within a few per cent.

The observed age in $D_2O$ is about 110 $cm^2$, a discrepancy of some 10% between calculation and experiment still remains to be resolved.

Although the absolute values of the densities of the two liquids differ by some 10%, the values of $\frac{1}{\rho} \cdot \frac{d\rho}{dT}$ (which is of importance in determining the moderator temperature coefficient of $H_2O$ and $D_2O$ systems) are very nearly equal.

N. BATTLE, C. C. HORTON

## ORGANIC LIQUIDS

THE consideration of organic fluids, particularly the aromatic hydrocarbons, for reactor applications both as moderators and coolants has been prompted by their generally low corrosivity, low residual reactivity from neutron capture, and their low vapour pressures at useful temperatures. Their high hydrogen content makes them excellent moderators. Since they become only slightly radioactive through neutron capture by dissolved impurities they do not require extensive shielding. The presence of combined oxygen often decreases thermal stability and introduces the possibility of undesirable and non-reversible side reactions whilst the presence of uncombined oxygen can lead to the formation of compounds decidedly corrosive to metal components.

The inability to form solid deposits of carbon or other insoluble residues is a most important requirement when operating at high temperatures and fluxes since these will tend to foul heat transfer surfaces and lead to failure of the fuel elements. The selection of a suitable organic fluid has narrowed itself down to relatively few compounds of which the class known as polyphenyls, and in particular diphenyl and terphenyl have received the greatest attention.

The main disadvantage to such materials arises from the chemical changes produced by high temperatures and the presence of ionizing radiations, both of which contribute to a gradual conversion of the original material to gases or 'polymers'. Their accumulation increases the viscosity of the fluid mixture and under prolonged irradiation might encourage further polymerization to products of still higher molecular weight or to carbon.

For a number of organic materials, particularly the nonaromatics, it has been established that the rate of decomposition on exposure to irradiation depends upon the absorbed energy whether produced by gamma radiation or by neutron moderation. With the polyphenyls however, investigations have shown that fast neutrons can be more damaging to the fresh material, especially at high temperatures, and this difference can become important when extrapolating the radiation damage data from one facility to another in which the neutron to gamma ratio might be different. Although this is true for low concentrations of polymer, these effects are of no great significance for practical purposes if the polymer content is $> 17\%$, since above this level decomposition rates are independent of the radiation type.

J. LAMBORN

## BERYLLIA

IN the absence of radiation, beryllia is suitable at high temperatures in most coolant gases. However, mass transfer via vapour-phase hydroxide occur independent of water vapour above 1000°C. Thermal conductivity and thermal shock properties are very good. Beryllia is also a suitable matrix for dispersing fuels based on uranium dioxide. These properties appear to be best taken advantage of in a small high temperature system.

The effect of fast neutron damage on physical properties and dimensional stability, and the cost, and difficulties of fabrication may impose limitations on this use.

Very few studies of the irradiation behaviour of beryllia have been made, and the majority of the data available refers to tests made below 200°C. The observed magnitude of changes in physical properties differ between investigators. This variation may in part be attributable to variation in density and melting of specimen preparation; all investigators agree that irradiation growth occurs but it has not yet been unequivocally established whether this growth saturates short of specimen disintegration.

High temperature studies in the irradiation fields have been confined to post-irradiation annealing. A bubble formation reported by French investigators has not been confirmed by work in the UK.

Current research on irradiation damage, both here and the USA is directed to answering whether or not lattice instability is due to a temperature dampening non-saturating component, and to defining over a range of temperatures the irradiation dose at which gas production becomes troublesome.

Beryllia of greater than 95% theoretical density can be prepared by hot compacting. Unadulterated beryllia being proved difficult to fabricate to consistently high densities by cold compacting and sintering. High purity beryllia is now commercially available and much of the fabrication effort available is devoted to sintering studies using such material.

J. WILLIAMS

# COOLANTS

*No cheap coolant yet combines good nuclear and heat transfer properties with low chemical reactivity and safety, and the choice for high temperature applications is still open*

## CARBON DIOXIDE

ALTHOUGH the compatibility of carbon dioxide with the graphite moderator, steel pressure vessel and magnesium canning alloy of the Calder reactors is satisfactory at normal operating temperatures, the oxidation reaction between carbon dioxide and fuel element materials could become of importance under fault conditions.

In a graphite moderated system, the coolant temperature is limited by the reversible reaction between carbon dioxide and graphite.

This limit has yet to be precisely defined but it is expected that at a

maximum temperature of 600°C to 700°C, the rate of the forward reaction at hot spots and the rate of the carbon deposition reaction at cool spots in the system would lead to unacceptably high rates of carbon transfer. Compatibility problems also arise at high temperature between carbon dioxide and the canning, structural and pressure vessel materials—beryllium, stainless steel and mild steel. The resistance of these materials can be affected by contaminants such as carbon monoxide and water vapour and it is important to control their concentration. At present it appears that compatibility with carbon dioxide is unlikely to be a problem, provided that the surface temperatures of beryllium and stainless steel cans are kept below 650°C and pressure vessel temperatures below 350°C.

One of the uncertainties at Calder Hall was the extent to which compatibility would be affected by irradiation. Four years' operating experience has shown that it is quite possible to measure the density loss of the moderator due to the reaction between carbon dioxide and graphite; it has also shown that deterioration of the graphite is unlikely to affect the life of the reactors. Extrapolation of these measurements taken together with controlled irradiation experiments in high flux test reactors, indicate that a carbon dioxide cooled graphite moderated reactor could be operated at a rating of at least five times that of the Calder reactors and that the rating can be further increased by the adoption of measures designed to reduce the rate of the carbon dioxide graphite reaction.

Operation of the AGR prototype reactor at Windscale should enable the ultimate limits on the use of carbon dioxide as a coolant to be more clearly defined.

P. C. DAVIDGE

## HELIUM

HELIUM has good nuclear properties and heat transfer properties comparable with carbon dioxide. It is chemically unreactive and therefore gives rise to the minimum of compatibility problems. The only drawbacks to its use are its restricted availability and high cost.

Helium is found as a constituent of the natural gas associated with some oil wells in USA and Canada. Extraction and purification plants have operated for some years in USA and the production capacity of the plants is in the region of 450 million ft³/year. The approximate price for helium delivered in Europe in bulk is £30/ft³. At this price it would cost £15,000 to fill one reactor at Calder; the comparable charge for a filling of carbon dioxide is £300.

Although helium is chemically inert, some chemical compounds of helium such as tungsten helide ($WHe_2$) have been identified. This has led to consideration of the possibility of helium being activated by reactor radiation to form transitory compounds with reactor materials and cause corrosion of the materials. To date, there is no evidence that such reactions do actually occur.

The chemical inertness of helium makes its use attractive for high temperature reactors. At these temperatures, however, impurities in helium become of importance and traces of carbon dioxide can, for instance, cause appreciable rates of mass transfer of graphite to occur. Impurities can be present in the make-up gas to the reactor and can also desorb from reactor materials, such as graphite and steel, particularly when these are heated. Continuous purification of helium is therefore necessary.

The future use of helium as a reactor coolant will, to a large extent, be determined by the gains that can be derived from high temperature reactor operation compared with the cost of constructing a reactor that has a negligible leak rate.

P. C. DAVIDGE

## NITROGEN

NITROGEN compares unfavourably with carbon dioxide and helium for both heat transfer and nuclear properties but is less chemically reactive than carbon dioxide and is cheap compared with helium.

Loss of nitrogen as a coolant would also result in loss of neutron absorber and would leave an operating reactor in a supercritical condition. This problem can probably be overcome by the use of automatic shut down devices but becomes more severe the higher the gas pressure.

Nitrogen and graphite are certainly compatible at temperatures less than 1000°C and in this respect, nitrogen is superior to carbon dioxide. There is no evidence of any reaction between nitrogen and carbon in the presence of radiation although attempts have been made to detect cyanogen formation.

The compatibility of nitrogen with structural and canning materials does, however, impose a limit on its use. For instance, it is known that steel exposed to nitrogen at temperatures above 1000°C will form a surface nitride which results in embrittlement of the surface. It has also been speculated that atomic nitrogen formed by irradiation of nitrogen will tend to react more readily than unirradiated nitrogen with metals.

The most promising use of nitrogen appears to be as a cheap coolant for a high temperature gas reactor but more work will be needed on the rate of formation of metal nitrides under reactor conditions before it will be possible to assess the limitations to its use.

P. C. DAVIDGE

## WATER

VALUES of Cp, k and $\mu$ are well documented for light water and light water steam, but values for heavy water are less readily available, and there is some scatter in the reported values. Information on compressed heavy water and heavy water steam is particularly scarce.

(*a*) Specific heat Cp, of heavy water. The ratio $Cp_{H_2O}/Cp_{D_2O}$ rises linearly from unity at 100°F to 1·035 at 400°F.

(*b*) Conductivity *k*, of heavy water. The ratio $k_{H_2O}/k_{D_2O}$ is 1·0519 at 212°F rising linearly to 1·1345 at 500°F.

(*c*) Dynamic viscosity $\mu$ of heavy water.

The ratio $\mu_{H_2O}/\mu_{D_2O}$ is 0·84 at 100°F rising linearly to 0·92 at 400°F.

N. BATTLE, C. C. HORTON

## ORGANIC LIQUIDS

A DISADVANTAGE inherent in organic coolants is that they have a heat transfer coefficient lower than those of the more common coolants such as sodium and water, but this is offset by the freedom to operate with a higher temperature difference between the fuel element can and the fluid.

No organic coolant can operate at a bulk temperature substantially greater than 400°C on account of a rapidly accelerating rate of thermal polymerization. In the polyphenyls however there is an absence of breakdown to elemental carbon for temperatures up to 500°C; accordingly fairly high localized temperatures can be tolerated, e.g. up to 460°C and possibly higher as in the case of fuel element surfaces.

The desirable properties of any organic material selected for use as a moderator or coolant can be summed up as follows:

(1) High thermal and irradiation stability; bulk temperatures up to 400°C should be possible with no higher than 0·1% breakdown.

(2) The absence of breakdown to ele-

mental carbon for temperatures up to at least 500°C.
(3) The formation of polymeric products which are completely soluble in the monomer.
(4) A low vapour pressure permitting a low operating pressure for the generation of steam.
(5) Low viscosity and other suitable physical properties for heat transfer.
(6) Good neutron moderation properties.
(7) The absence of corrosive action with constructional materials.
(8) The absence of a high level of induced radioactivity in the circuit.
(9) Ease of separation of radiation by-products from the monomer.
(10) Cheapness.
(11) Low melting point.

At the moment research is being carried out both into methods of reducing damage rates in existing polyphenyl coolants (e.g. by the addition of small quantities of inhibiting agents), and also at assessing commericially available by-product materials such as refinery off-cuts having low replenishment costs.

J. LAMBORN

## HYDROGEN

REACTOR cores must be tailored to fit the properties of the chosen coolant. Useful guides to the choice are, however, the pumping power required and the total heat output achieved. In both cases hydrogen shows marked superiority. Choice of high temperature canning material would be limited to stainless steel, beryllium, or graphite. Reaction of hydrogen with graphite would probably be acceptably slow even though thermodynamically favoured. Hydrogen diffuses through metal walls and leaks through circuit defects faster than other gases. These losses would be small relative to leakage. Leakage could be reduced to acceptable levels by care in design. To do this design standards would have to be better than those currently used for $CO_2$ cooled reactors.

No rational basis exists for the design of pressure vessels to withstand explosion or detonation. Explosion proof design would in any case be uneconomic. It would therefore be necessary to guarantee that an explosive mixture could never be formed. This has been the principal reason for rejecting hydrogen for reactor cooling.

Circuit rupture of a power reactor would have serious consequences. Conditions would be less restrictive in nuclear rocket propulsion where the additional advantages of low weight makes hydrogen an attractive proposition.

Growing confidence in ability to handle hydrogen safely may alter this picture.

D. BRADLEY

## LIQUID METALS

THE chief problems associated with sodium and NaK are due to their high chemical reactivity and avidity for oxygen, resulting in the need to contain the coolant in a leak tight system, usually all welded, under an inert gas cover. Nitrogen, argon or helium are used as cover gases though argon becomes active under neutron irradiation and, under certain conditions, nitrogen can lead to nitriding of stainless steel circuit components. Pure sodium has non-corrosive properties for structural materials with which it does not alloy but a few p.p.m. of impurities, especially oxygen, hydrogen and carbon, confer corrosive and and other undesirable properties upon it. Control of impurities is exercised by cold trapping or high temperature gettering processes. Cold trapping entails reducing the temperature of part of the coolant below the saturation temperature of the impurities in solution and trapping the precipitated material by a filter medium. Gettering processes involve a reaction between the impurity in solution and a selected getter at high temperatures, e.g. zirconium is a useful getter for oxygen and high chromium stainless steel for carbon. Measurement is often difficult at the levels encountered for specific impurities though in line instruments based on measurements of electrical resistivity and saturated solubility temperatures are in use. Development work is continuing on the methods of control and measurement of impurities.

Electromagnetic pumps are still employed on smaller development circuits but on larger power reactors, following development work on submerged bearings, shaft seals and canned rotor/stator units, mechanical pumps are now seriously considered. On power producing reactors considerable research is being carried out not only on basic heat transfer data but on the design of heat exchangers to promote efficiency without increasing the safety hazards of a mechanical failure bringing the coolant into contact with water.

K. HARGREAVES

# ABSORBERS

*New materials under development may yet rival boron and hafnium*

## BORON

NATURAL boron, containing 18·8% of the isotope B-10 is of considerable technological importance for control and burnable poison materials. The capture of thermal neutrons by the isotope however results in the formation of additional atoms producing high material stresses. In addition, the energy of the 'fragments' is dissipated locally in the material and causes further damage to the lattice.

Attempts have been made to limit the radiation damage by alloying or otherwise dispersing the boron in a strong and ductile matrix. 3·8% boron steel extruded tubes and 5% boron steel cast tubes sheathed in austenitic stainless steel have been used as control rods in the Calder Hall type reactors. In the USA considerable effort has been directed towards the development of alloys of boron with stainless steel, zircaloy-2 and titanium and of boron carbide ($B_4C$) in its pure state and dispersed in diluents such as alumina, zirconium and austenitic steel. Increasing boron content generally increases hot shortness and makes working more difficult for all the alloys.

American investigations suggest that irradiation causes some increase in strength and a marked loss in ductility with increased B-10 transmutation. In boron-austenitic stainless steel alloys, these effects are sufficiently harmful to make the alloys of doubtful value after burnup of B-10 in excess of 1–2 at-%. Radiation growth also occurs in these alloys. No growth appears to take place until about 0·7% of the total atoms have been transmuted but above this value, growth is rapid and proceeds at rates near 3 vol-% per at-% B-10 transmuted. At higher burnups, the swelling rates appear to decrease. Extensive physical damage occurs in boron carbide beginning

with loss of hardness and cracking after very low burnup and increasing such that complete granulation occurs after 36% burnup. Zirconium boride ($ZrB_2$) appears to be able to withstand higher burnup of the B-10 atoms than boron carbide with respect to helium retention and further, is also able to withstand temperatures up to about 540°C without exhibiting excessive helium release.

The continued use of boron for control rods is markedly dependent on the swelling characteristics which may be accentuated as operating temperatures are increased. Alloying of boron with materials having sufficient creep resistance to withstand the helium gas pressures may be a step in the right direction and further improvements in properties, especially ductility, may well be obtained by vacuum melting the alloys.

D. R. HARRIES

## HAFNIUM

HAFNIUM is an ideal control rod material for pressurized-water reactors. Its corrosion resistance is excellent, and is considerably better than that of the zirconium alloy used in PWR fuel element manufacture (silver alloys which appear to offer an attractive alternative on economic grounds are much less resistant to corrosion and their radioactive corrosion products are a source of coolant contamination). Its mechanical strength is similar to that of zirconium. Irradiation causes an increase in hardness and proof stress, with a corresponding reduction in ductility, but the changes are not significant during the life of a single core. Serious irradiation damage (for example, the swelling of boron by gaseous inclusions) does not occur in hafnium, and there is no phase change in the normal working temperature range.

Hafnium has a high thermal and epithermal neutron absorption cross-section and its worth remains high during irradiation. Most of the absorption cross-section is provided by the isotopes Hf-177 and Hf-178 but transmutation produces successively higher isotopes, each with a significant absorption cross-section.

*Possible developments* 1. The production of hafnium ingot by the electron-beam melting of high-purity sponge may supersede the iodide refining process and the subsequent consumable arc-melting of crystal bar. The electrodeposition of hafnium in a fused-salt electrolyte is also being developed as a possible alternative method of refining sponge and scrap hafnium.

2. Improved refining techniques are giving a progressively purer hafnium metal whose hardness, proof stress, and corrosion resistance may be inadequate for control rod manufacture. Small impurity additions (notably oxygen) can be used to restore these properties and there appears to be scope for the development of a hafnium alloy with improved properties.

3. The thickness of hafnium control rods, determined on strength grounds, is normally more than is required to provide a 'black' absorber throughout core life. It follows that the proportion of hafnium could be reduced without affecting the rod effectiveness. There is scope for developing a hafnium alloy, with adequate mechanical and nuclear properties, which would be cheaper than pure hafnium. If by this means the ratio of hafnium to zirconium requirements could be reduced to the natural abundance ratio of the two metals (about 2%) the economic efficiency of the separation and refining processes would be improved.

S. E. GOOD

## RARE EARTHS

SOME rare-earths have high neutron absorption cross-sections and can be considered as possible reactor control materials. Average thermal cross-sections compared with hafnium and boron are as follows:

| | | | |
|---|---|---|---|
| Hafnium | 90 barns | Gadolinium | 40000 barns |
| Boron | 650 „ | Dysprosium | 950 „ |
| Samarium | 4570 „ | Erbium | 145 „ |
| Europium | 4000 „ | Lutecium | 95 „ |

Due to its very high cross-sections gadolinium would suffer very fast burn out and has therefore limited application, i.e. in low burn-up conditions only. The most promising element for practical application is europium and it is considered that a 20% dispersion of europium oxide in stainless steel is approximately equivalent to massive hafnium in control rod effectiveness. Experiments carried out with small size sintered europium-oxide and gadolinium-oxide stainless steel plates in a zero-energy experimental reactor have indicated an approximate equivalence to hafnium.

*Fabrication* This type of material can can be fabricated in a number of ways:

1. Sintering or hot-pressing the oxide either alone or mixed with another refractory oxide as a diluent to form a ceramic.
2. Cold compacting followed by sintering of a cermet consisting of 20% $Eu_2O_3$—stainless steel, the final shape being obtained by machining. This method has been applied to the fabrication of small plates, cold-pressing of the powder being carried out at approximately 40 tons/in² followed by sintering 4 h at 1200°C. The final density was approximately 90% of the theoretical, but no doubt this could be improved by higher compacting pressures and longer sintering times. The product was quite easily machined to the shape required.
3. Hot rolling the cermet compact either in the green state or after partial sintering using the picture-frame technique. This method would also enable the cermet to be completely clad.
4. Co-extrusion methods. Experimental, clad Y-shaped control rods have been produced by this method in the USA.

M. L. PARKER

# SHIELDING

*Attaining the required weight per unit area of shield in an economical manner is the main aim; many materials show promise*

## CONCRETE

THE ability to withstand temperatures higher than 80°C and to retain sufficient hydrogen at these temperatures are the most desirable properties for a shield concrete. Some success has been achieved recently in attempts to obtain concretes adequate in this respect.

### Portland cement concrete

USED for bulk shields of thicknesses greater than 6 ft the rate of loss of water has been found to be negligibly low, except in regions within about 3 in. of the surface. This type of concrete is dimensionally stable and may be placed to the accuracy required in the construction of complicated forms required in reactor shield construction.

Both neutron and gamma radiations are suitably attenuated, but the gamma is more penetrating and usually contributes the most to the dose rate when the shield thickness is greater than about 6 ft. It is because of this that attention has been focused on heavy aggregates for more dense concretes.

The presence of reinforcing steel in most large concrete shields complicates the problem of estimating the dose-

rate and the need exists for more precise flux attenuation measurements. Some work on this subject is in progress at present.

### Heavy aggregate concretes

AN improvement in the shielding properties of concretes can be made by substituting aggregates and fines, which have higher densities or constituent elements of high atomic number, in place of gravel and sand. Some of the more noteworthy concretes used in this country are described below.

*Barytes concrete* This concrete is more difficult to place than gravel concrete because of its higher density but is just as structurally sound. It is particularly useful where high energy gamma attenuation is required, i.e. in reactor shields. Since it is more costly than gravel concrete it is therefore only used where the available space is limited.

*Iron shot concrete* is more economical than Barytes concrete and is very useful for reducing the thickness of bulk shields. It is excellent as a gamma shield. When used in reactor shields the heat generation becomes a problem. Since the energy absorption will be mainly in the iron, local temperature gradients may be severe and differential expansion may cause deterioration. This aspect has not yet been fully investigated. Furthermore, this concrete can be used in dry locations only, since a damp atmosphere causes corrosion of the iron and consequent deterioration of the concrete.

### Significance of hydrogen content

Recent investigations indicate that if the water content of concrete falls below 4% by weight, the neutron shielding efficiency is impaired, on the other hand, no great advantage is obtained by increasing the water content above 7% by weight. Granite concrete of density 2·5 gm/cm$^3$ contains about 4½% of water by weight.

Increased water content is to be desired, particularly if the neutron shield is to be of high density.

The use of hydrogenous aggregates appears to be the best means of obtaining concretes of high density and high water content. Specimens of concretes with British aggregates have not yet been tested but by analogy with some American concretes they should prove satisfactory.

A disadvantage of all the foregoing concretes is the loss of water with rising temperature; 50% of the water of hydration and all the interstital water may be lost if the temperature exceeds 100°C. In some concretes disintegration may commence at temperatures as low as 120°C. It is therefore necessary to prevent overheating of these concretes by providing thermal shields or cooling.

Two other types of concrete are available which are not subject to such temperature limitations. These are: Serpentine Concrete and Borocalcite Concrete.

*Serpentine concrete* Results of tests made in the USA indicate that concrete containing Serpentine rock will hold most of its initial hydrogen content for periods of over ten years at temperatures up to 800°F.

The concrete can be applied with advantage to regions in the reactor shield structure which are exposed to relatively intense neutron radiations and are at high temperatures but only lightly stressed. It is especially suitable for the top biological shields of large thermal power reactors, where the shield is displaced unavoidably, by arrays of standpipe penetrations. The conditions in regions adjacent to the main coolant ducts and the floor of the reactor vault can be improved with the use of this material as a shield.

An alternative application of the Serpentine rock is the use of finely powdered material in steel containers to form shield plugs, where local neutron shielding at high temperature is required. Densities of 130 lb/ft$^3$ have been achieved for the rock in this form.

Further development, to determine the optimum aggregate size and mix proportions of the concrete is likely to result in improved structural properties.

*Borocalcite concrete* Recent tests have shown that concrete of strength equal to the ordinary Portland concretes with a setting time of 3½ h can be made containing up to 7% of Borocalcite of Colemanite ($2C.O.3B_2O_3.5H_2O$).

The presence of boron and a water content of about 6% by weight gives improved neutron attenuation, a softer capture gamma spectrum and a lower total heat generation rate when used as a reactor shield.

*Borated diatomaceous-earth concrete* Concrete with diatomaceous-earth as the aggregate has been developed recently in the USA with the object of achieving a high temperature neutron shielding material. It is claimed to be capable of withstanding temperatures up to 2000°F and has a compressive strength of greater than 1000 lb/in$^2$.

The main applications for this material are clearly those sections of the reactor shield which demand a material capable of attenuating neutron radiation and which is an efficient thermal insulator. These sections of the reactor building are the biological shield plugs, regions near the main coolant ducts and the inner parts of the reactor vault generally.

The relatively low density of the concrete makes it unsuitable as a gamma radiation shield without the addition of a layer of other suitable dense material. The development of this concrete as a thermal shield material in place of the usual iron layers could show some advantage in cost.

## NON-METALS

### Resin-impregnated wood

THIS material is in the form of resin-bonded wood laminate. It is suitable for neutron shielding in conditions of relatively low neutron fluxes and temperatures up to 150°C. It is used as neutron shielding on fuel charge-discharge machines, and in fuel storage areas to reduce the probability of criticality. The upper limit of 150°C on the temperature restricts the use of this material to the regions external to the bulk reactor shield.

### Polythene

RECENT development has been aimed at producing initially bubble-free blocks of uniform density containing evenly dispersed boron. This quality of borated polythene is now being produced, and is suitable as a neutron shield to reduce background radiation in the vicinity of instruments or as an external layer to attenuate neutron radiation which could otherwise escape from gaps in main shields.

The softening which occurs at temperatures above 60°C limits the use of polythene to regions remote from any heat source. Furthermore high intensity irradiation produces free hydrogen in the material which causes bubbling and swelling—hence the use of the material is limited to low flux regions.

## BORON

### Calcium borate

A MATERIAL composed of borated calcium minerals in a matrix of asbestos has been produced in the USA. Irradiation tests show that the material will withstand, without deterioration, an integrated dose of $2\times10^{20}$ nvt and can be used at temperatures greater than 1000°F.

This material is suitable for shielding in regions of relatively high neutron flux and high temperatures. It is being applied to the gaps in the biological shield of the Enrico Fermi reactor around the hot coolant ducts to reduce neutron streaming.

The rather low density and low hydrogen content limit the use of this material to local regions in main shields where these deficiences can be made up by other adjacent materials. Its usefulness as a 'thermal' shield and its usefulness in reducing radiation damage to other materials near the reactor will be investigated.

### Boral sheet

IMPROVEMENTS have been made recently in the manufacture of boral sheet. Originally the process was one of sintering boron carbide with aluminium powder and pressing between aluminium sheets. The resulting sheet was expensive and not workable. The present boral sheet is made by mixing boron carbide powder with molten aluminium and hot rolling between aluminium cladding. The new boral is cheaper (about £3 7*s* 6*d*/ft² 0·18 in. thick) and can be worked with the freedom of aluminium itself.

Where this material is used within the reactor vessel the edges must be sealed to prevent contamination. Its use in such localities is limited by the loss of strength at the temperatures reached. The self heating due to thermal neutron absorption will be quite high. Because of these two reasons and its cost, it is seldom used inside reactor vessels, even though it is otherwise an attractive shield material. Boral is not compatible with concrete.

### Boron steel

A SECOND method of containment for boron is to alloy it with steel. Additions of up to about 10% of boron may be made, but with over 2% of boron the steel is difficult to machine. Little is known about the corrosion rate of unclad boron steel under reactor conditions but it should not vary considerably from that for comparable steels which have been tested. The rate of transference of boron from such steels by coolant is unknown and requires investigation. It is preferable that all boron steels be clad where there is contact with the coolant.

Compared with 0·18 in. boral plate the thickness of boron steel plate would be about 1½ in. thick to give the same thermal neutron attenuation. The costs would be comparable. When cladding is added to the boron steel then the cost is increased. The cost of stainless boron steel is so high that it warrants a full investigation of boron transference from the steel by the coolant before using this steel in preference to boron steel clad with mild steel.

It is sometimes overlooked that the inclusion of about 2% of boron in stainless steel does not eliminate thermal neutron capture in iron so that there will still be a high energy capture gamma spectrum and residual activity, particularly if the boron steel is clad on the reactor side.

## OTHER METALS

### Lead

THE application of lead as shield material has been extended by several manufacturers mainly by combining it with other dissimilar materials. Bonded mixtures have been produced which have, to some extent, the properties of lead for gamma radiation attenuation and the elastic or the neutron attenuating properties of the other material. Examples of these products are lead-rubber, lead-polythene and lead-resin-wood.

Leaded-rubber may be used in relatively low neutron and gamma fluxes as a sealing or packing material where flexibility is advantageous, e.g. to shield the irregular gaps between massive shield blocks. Lead-polythene and lead-resin-wood can be applied in the form of blocks for temporary shielding of experimental facilities or, of course, in place of separate layers of lead and polythene or lead and resin-wood as secondary shielding of marine and other small research reactors.

### Cast iron

IN the form of standard blocks, this material forms a simple and effective gamma shield. Attempts are being made to establish a minimum density to casting size relationship for cast-iron supplied for shielding purposes.

### Zinc bromide solution

ZINC bromide is one of the most soluble salts which produces a colourless transparent solution. The solution can contain up to 80% of zinc bromide by weight and achieve a density of 2·5 gm/cm³. The solution is chemically stable although corrosive to mild steel. Its main use is for windows through thick shields for which purpose it is contained in a stainless steel or plastic tank with glass ends (the inner glass being radiation stabilized).

### Discussion

Because most concretes lose water more rapidly as the temperature rises above 80°C it is essential to limit the radiation heating in the concrete. The majority of this heating is due to absorption of gamma radiation produced by capture of thermal neutrons.

There are some 40 elements which have capture cross sections greater than that of iron (2·5 barns), ranging from gadolinium (38,000 barns), through cadmium (3300 barns) and boron (755 barns). Due to the comparatively high costs, low melting points etc. of the other elements, only cadmium and boron compounds can be considered competitive with iron or steel. A steel thermal shield gives some attenuation of the capture gammas produced in the shield. By comparison, a cadmium shield equivalent for thermal neutron capture would be too thin to give appreciable self absorption of the gamma radiation. Boron, however, produces only low energy gamma radiation and the amount of heating is less than half of the total heating produced by either iron or cadmium. With the boron thermal shield there will be little attenuation of the gamma and fast neutron components arising in the core. Therefore unless some specific condition is required e.g. reducing the activation of the pressure vessel and concrete, steel is preferred as a thermal shield material.

The main aim in choosing material for gamma radiation shields is to attain the required weight per unit area of shield in an economical manner. Suitable materials should be reviewed with respect to cost and attenuating properties. A good approach is to obtain the 'relative values' of the materials on the basis of the macroscopic cross section for the reaction and cost, i.e. assume that 'relative value' $R = \mu/\text{cost}$ where $\mu$ = absorption coefficient, cm$^{-1}$ cost is given in units of shillings/ft³. The table gives some 'relative values' referred to ordinary concrete as unity.

| SHIELD MATERIAL | RELATIVE VALUE FOR 1·5 MeV PHOTONS |
|---|---|
| Ordinary Concrete (Whinstone Aggregate) | 1 |
| Water (untreated) | 556 |
| Common Brick | 0·988 |
| Iron Shot Concrete | 0·913 |
| Lead | 0·837 |
| Steel | 0·829 |
| Barytes Concrete | 0·546 |

Note that the costs include placement of concrete and brick and erection of steel. The cost for lead is material only, and for water, only the pumping charges are included.

From these results it is clear that in cases where water is impractical, ordinary concrete or brick is the cheapest shield. Where space is restricted iron shot concrete may be used if the conditions are dry, otherwise the choice is steel, cast iron or lead.

A. JACKSON, E. W. SIDEBOTTOM

# COMPONENTS

*Under investigation: the effect of very high energy neutrons on steels . . . the use of large precast concrete items . . . the future of silicon carbide*

## FERRITIC STEELS

RECENT investigations at Harwell have been concerned with determining the effects of neutron irradiation at 50°, 130° and ~ 300°C on the ductile-brittle transition temperatures of Charpy V-notch specimens, machined from welded plates of mild and low alloy steels suitable for reactor pressure vessels, and tested in slow-bend. The maximum irradiation embrittlement appears to occur at an irradiation temperature of about 130°C. The fast neutron dose was measured using sulphur monitors and assuming a cross-section of 65 mb for the S-32 (n,p) P-32 reaction.

The semi-empirical relation between the increase in transition temperature ($\triangle T$) and the integrated neutron dose ($\phi$) ($\triangle T = A\phi^{\frac{1}{2}}$) derived by Cottrell is based on measurements of the integrated thermal neutron dose under conditions where the ratio of thermal to fast neutron flux is about 10 : 1. However, thermal neutrons do not cause radiation damage in steel. It is believed that most of the embrittlement is caused by the group of neutrons with energies greater than 1 MeV and, if this is so, the very high energy end of the neutron spectrum in reactors is the most important. The threshold of the S-32 (n,p) P-32 reaction is about 3 MeV and so this measurement of the fast dose is probably suitable for correlation with radiation damage.

Assuming that the $\phi^{\frac{1}{2}}$ dependency is obeyed, all the results for the steel parent plate, weld metal and heat-affected zones irradiated at 130°C lie within a scatter band defined by $\triangle T = 27{\cdot}3\,\phi_s^{\frac{1}{2}}$ and $\triangle T = 56{\cdot}7\,\phi_s^{\frac{1}{2}}$.

Thus, the results indicate that where a pessimistic rather than the mean estimate of the dose dependence is required, the relation $\triangle T = 55\,\phi_s^{\frac{1}{2}}$ is suitable, where $\triangle T$ is in °C and $\phi_s$ is the sulphur dose in units of $10^{18}$ n/cm².

At the US Naval Research Laboratory investigations have been made on Charpy V-notch and miniature Pellini drop weight ($2 \times 5 \times \frac{5}{8}$ in.) specimens of several steels and welds representative of heat-treated reactor pressure vessel material. There is a straight line relationship between the increase in transition temperature as measured by the 30 ft-lb temperature in the Charpy impact test and the increase in the Nil Ductility Transition (NDT) temperature in the small size drop-weight test.

Post-irradiation annealing studies at ORNL on mild steels have shown that the recovery begins at temperatures between 260°C and 315°C with 1½ h annealing periods. The rate of recovery increases with increasing neutron dose at 60°C and specimens irradiated at 300°C do not recover as rapidly as specimens irradiated to the same dose at 60°C.

Future work on irradiation effects must include detailed studies of parameters such as neutron dose, neutron energy, instantaneous neutron flux, exposure temperature and recovery characteristics, coupled with extensive investigations of type of steel, grain size, etc. before optimum use can be made of mild and low alloy steels in nuclear reactors.

D. R. HARRIES

## CONCRETE

THE total cost of the concrete used in a typical nuclear power station is greater, with the exception of the uranium, than that of any other single material. Most of the properties of concrete are well understood but there are gaps in present knowledge about its behaviour under elevated temperature conditions and about its structural integrity after prolonged irradiation.

Successive tensile and compressive strain patterns of an unknown magnitude are engendered by phenomena operating during the setting and hardening of a biological shield. These phenomena include, *inter alia*, heat of hydration, drying shrinkage, creep, and thermal movements.

The strains before commissioning are thus indeterminate and the designer then investigates, by the present arbitrary techniques, the further strains resulting from operational temperature differentials.

If prestressing wire is present in the shield, the effect of irradiation on high tensile steel has to be allowed for in the design.

*Recent developments* The most significant current development is the use of concrete as a combined biological shield and pressure container. The proposal does not merely eliminate the steel pressure vessel; it also markedly improves the safety of the structure against the hazards of temperature and pressure excursion.

Other current developments in design philosophy include a better appreciation of thermal stress problems, a widening use of specially-heavy shielding concretes, and the use of very large precast items.

*Present and future research* Values of creep and shrinkage tend to vary with time, temperature and stress level. Work is currently in progress at several establishments to investigate these relationships. Simon-Carves Limited of Stockport have, for example, undertaken a series of thermal stress experiments to evaluate the factors affecting the stressing of concrete under temperature gradients. The object is to simplify the approach to thermal strain-resistance in concrete shields by identifying the optimum relationship between concrete area, steel reinforcement, and shield cooling system.

S. GILL

## SEMICONDUCTORS

TWO examples of the contribution that semiconductor research has made to nuclear engineering are the purification of metals to less than 1 part per billion by the zone refining technique, and the original work by McKay on radiation damage in *pn* junctions.

The desire for devices with higher operating junction temperatures than those currently available in germanium (100°C) and silicon (200°C) has given impetus to the exploration of other semiconductor materials with a larger energy gap, such as gallium arsenide and silicon carbide which in turn will permit maximum junction temperatures in excess of 300°C.

Due to the more complex metallurgy of these new materials control of purity and perfection has not yet reached the advanced stage of that in silicon and germanium. However, there is already a gallium arsenide tunnel diode commercially available. It has the added advantage of being able to withstand a higher radiation level than the equivalent germanium device.

Semiconductor neutron detectors have already been made available in the USA, the miniaturization and special resolution in neutron flux plotting is of great value. The possibility of extending semiconductor detectors to cover alpha and beta counting has been demonstrated.

P. H. STEPHENS

Patient development work has overcome such problems as the limited space in reactor experimental holes, the suspect nature of heat transfer calculations, and the difficulties of temperature control of specimens

# Irradiation techniques for fissile materials—1

*by O. S. PLAIL, A.M.I.Mech.E., Group Leader, Irradiation Branch, Metallurgy Division, AERE, Harwell*

THE VARIOUS GROUPS of tests forming the bulk of fissile irradiation work in support of reactor technology can roughly be divided into three:

(1) Full size fuel element testing in a power or production reactor. This is a statistical approach involving large numbers of either standard or near standard fuel elements and is a vital part of the experimental process because only in such tests can overall reactor conditions and effects be studied. This type of experiment must inevitably take a long time to obtain results because heat output (i.e. fissile content), cartridge dimensions etc., must conform closely to normal standards for the reactor in which the tests are being carried out.

**OUTLINE**

This is the first of a series of articles describing the evolution of some of the experimental techniques for irradiation testing of fuel materials developed for the Irradiation Group in the Metallurgy Division at Harwell. In the USA and Canada, this type of work has been carried out for some 12 to 15 years at many establishments but in the UK, few experimental fissile irradiations took place before about 1950.

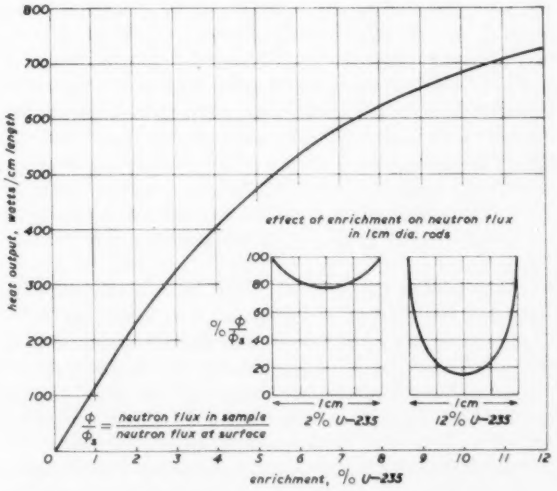
(2) Accelerated test using dynamic loops (i.e. rigs in which the coolant is pumped past the test specimens) in a test reactor. These tests frequently attempt to obtain information on near full size prototype fuel element behaviour in advance of the tests described in (1). Because of the relative smallness of most test reactors resulting in large flux gradients, the need for fairly substantial pressure vessels to contain the coolant and the need to use enriched material to speed up the tests, the experiments become a poor substitute for those under (1) and can seldom be statistical. There is, however, a type of loop testing which is most valuable (i.e. where environmental conditions are important) and in these circumstances, small dynamic loops with limited heat output to accommodate small specimens are frequently used. In the USA the large type loop is frequently used and reactors such as the ETR at Idaho are specifically designed to house such experiments. In the UK, however, the large loop is not popular although several smaller loops of the latter type have been used.

(3) Small scale irradiations where environmental conditions are of secondary importance provided they do not affect results. These experiments, which utilize specimens considerably smaller than full scale fuel elements, are essentially scientific in character. Their aim is to study irradiation damage and metallurgical effects in the fuel. As the tests are carried out on small specimens, a larger number of samples may be involved and thus a wider range of fuels may be studied than is possible in (1) and (2). Although these tests are no substitute for (1) because only the fuel is studied, they can give information of assistance in understanding reactor fuel element behaviour.

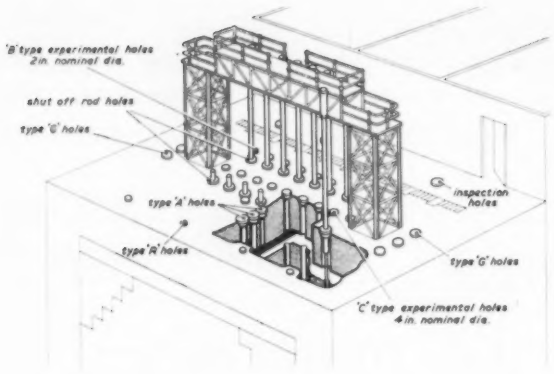
The problems involved both in the in-pile apparatus and the post irradiation equipment (to be covered in a later article) are complicated, involve the expenditure of very large sums of money and have required years of careful and patient development. The cost in money and effort has often not been appreciated in the past, and there has been a tendency to regard irradiation testing as merely dangling a piece of metal on a length of wire in a reactor.

## SPECIMEN CONSIDERATIONS

In the recent past, the bulk of the fissile irradiations carried out by the Metallurgy Division at Harwell has been


heat output, watts/cm length
enrichment, % U-235
effect of enrichment on neutron flux in 1cm dia. rods
% Φ/Φs
1cm
2% U-235
12% U-235
Φ/Φs = neutron flux in sample / neutron flux at surface

Heat output against enrichment for uranium metal specimen 1 cm dia. infinitely long, neutron flux at specimen surface $2 \times 10^{13}$ n/cm² s (Fig. 1)


'B' type experimental holes 2 in. nominal dia.
shut off rod holes
type 'G' holes
type 'A' holes
type 'R' holes
inspection holes
type 'G' holes
'C' type experimental holes 4 in. nominal dia.

Position of the experimental holes in a Windscale pile (Fig. 2)

on uranium and its alloys although some work has also been undertaken on ceramic fuels. Sample sizes have ranged from 0·5 g up to 200 g and resulting heat outputs from 20 W to 2000 W per specimen. Once an experimental programme has been decided, the specimen size and shape must be resolved before work can proceed. In choosing actual specimen parameters, these factors are involved:

(*a*) time to achieve required burn-up
(*b*) permissible heat output
(*c*) surface heat rating (this can affect the accuracy with which temperature can be measured)
(*d*) permissible thermal gradient in specimen
(*e*) ratio of burn-up outside/centre.

These inter-related factors are, to a large extent, controlled by the choice of the enrichment.

In thermal reactors, a law of diminishing returns applies to enrichment. As the enrichment increases, so does the average burn-up rate but not in direct proportion and a point is fairly rapidly reached where it is not worth increasing the enrichment because of the small gain.

In other words, the blackness of the specimen to neutrons increases rapidly so that specimen size is strictly limited or the enrichment gives rise to unnecessary low burn-up in the centre of the specimen (see Fig. 1).

The use of either enriched material or higher flux reactors, or both, for these small scale experiments speeds up the tests and leads to higher ratings and high fission and thermal gradients in the specimens. Thus if work is undertaken in support of a graphite moderated reactor of say the CEGB type, the test conditions may well be dissimilar to actual power reactor conditions. For tests in support of a fast reactor programme, the situation may be more complicated.

Interpretation of the results must be carefully done and although experiments of this type are relevant, the results should be judged with those obtained in comparable experiments and should not necessarily be translated directly to production fuel element behaviour. In spite of these difficulties, however, a wide variety of tests is possible in which the effects of many variables may be studied.

The other important factor influencing the choice of specimen parameter is the flux depression due to the test rig itself. This is very marked with some loop pressure vessels and it should be the aim of the rig designer to minimize this depression. In any case, a knowledge of the actual flux depression in a particular rig is essential and wherever possible, low power runs to measure this should be carried out on rig mock ups. It has been found that on average, the time spent by an experiment of this type in a reactor is perhaps only 25–30% of the total experimental time from inception to completed examination. Therefore, any speed up of irradiation time produces overall, a small percentage reduction in overall time but may increase technical difficulties disproportionately.

## GENERAL RIG DESIGN

The fundamental problems are threefold:

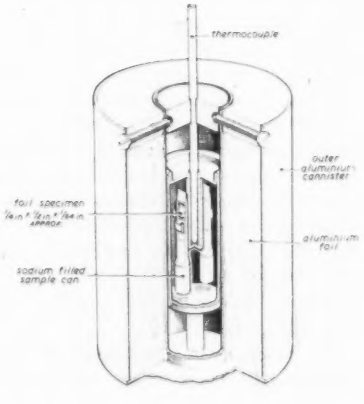
1. removal of heat generated during irradiation
2. control of temperature
3. accurate measurement of temperature.

These separate but closely linked problems become more severe in higher flux reactors. Moreover, there are frequent materials problems as many metals and plastics, which could be used in the laboratory, are unusable in the reactor due either to high absorption cross-sections, incompatability with other components or breakdown under neutron bombardment. One other difficulty often overlooked but frequently severe, is the very limited space available in the reactor experimental holes. From these general difficulties arise many detailed ones such as methods of introducing power and thermocouple leads, jointing these reliably in the reactor, permissible coolants and their containment, heater manufacture, operation and reliability etc.

## EARLY DESIGNS

In retrospect, early designs may not appear elegant but there was no previous experience or knowledge available. The difficult task had to be faced of obtaining reliable scientific data to a tight experimental schedule whilst developing the experimental apparatus and, therefore, untested techniques had to be used. Additionally, only a very limited quantity of fissile material was available.

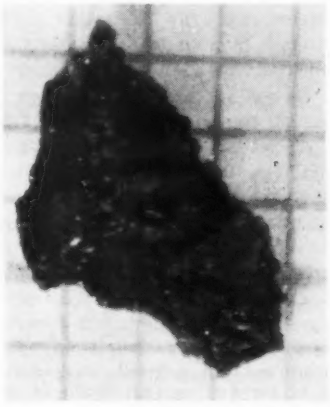
A very large proportion of the early experiments were in support of an advanced reactor program and information was required on the effect of high burn-up on metallic fuels. Apart from Bepo with an available flux of $10^{12}$ neutrons $cm^2/s$, no research reactors were then available in the UK so the work was carried out in the production reactors at Windscale, using the only available experi-




Type of canning used for the first foil specimens (Fig. 3)

mental holes. These were situated close to the centre line of the reactors and included both 4-in. and 2-in. holes which extend right into the reactor core (Fig. 2). The 4-in. holes on the reactor centre line were chosen for this work and liners of aluminium some 32 ft long and nominal 4 in. dia. were fitted in each. Each liner penetrated into the reactor so that the lower 12 ft or so was in the flattened region and a fairly uniform flux was experienced. It was essential that these liners were satisfactorily sealed at their lower end to avoid leakage of the reactor coolant. At their top end they were fitted with neutron shielding plugs.

The irradiation samples chosen had low heat outputs and no special cooling arrangements were incorporated, the heat being lost by natural convection and conduction to the liner and thence to the reactor coolant. The first samples irradiated in these facilities consisted of thin slices of highly enriched uranium 0·010–0·015 in. thick × 0·3 in. × 0·15 in. Figure 3 shows the first rig. Two specimens were contained in small thin-walled sodium filled stainless steel capsules which were held either side of a

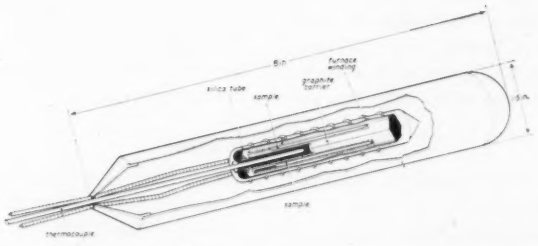


Coking shown by a piece of unalloyed uranium foil after irradiation (Fig. 4)

rather heavy thermocouple pocket inside a stainless steel can. This second can was incorporated as it had been agreed with the reactor group that where sodium was used, a double containment should be provided. It was further contained in an outer aluminium case lagged with aluminium foil. The first heat transfer calculations indicated that the specimens should operate between 500–600°C but, on insertion in the reactor, the temperature rose rapidly to well over 800°C and probably nearer 1000°C. The capsule was withdrawn into the biological shielding and allowed to decay radioactively for several weeks until it could be handled for a short time. The outer casing of the rig was then removed and the samples replaced in the reactor. The removal of this outer insulation layer reduced the temperature to approximately 500°C and the rig was left in the reactor to complete its burn-up. Subsequent examination showed that the short excursion above 700°C had caused the uranium and the stainless steel to alloy and the experiment was in a sense wasted.

Perhaps it was fortunate that this first experiment failed as this demonstrated the basic triple problems of heat transfer, temperature control and temperature measurement and immediate steps had to be taken to overcome the difficulties. Since then, laboratory mock-ups have been built wherever possible and heat transfer calculations regarded with considerable suspicion. This attitude is still adopted even with fairly advanced type of rigs now in use.

The next type of rig contained similar samples but the small capsules were now fitted with a barrier of zirconium between the steel and the uranium to prevent alloying. In addition, the outer stainless steel capsule was sodium filled to improve heat transfer and wound with a heater made from mineral insulated cable. Outside this, to conform to the double canning standard for sodium, was a third stainless steel can and outside this, an aluminium casing. This rig operated at 500°C for some two months before the heater failed. In sodium-filling this second can and supplying a heater, the principle of overcooling coupled with auxiliary heat to provide temperature control, was established, and this technique has been adhered to in all subsequent work.




Furnace used for irradiating single crystals at 500°C in one of the Windscale 2 in. holes (Fig. 5)

For these early experiments the measurement of total integrated neutron flux was tackled by a combination of calculations from known flux levels in the reactor and the insertion of cobalt monitors for subsequent activity counting. Even at this early stage, the evolving rig design was raising side problems such as the safe and efficient handling of sodium, sodium filling, handling techniques, welding of very thin stainless steel, heater development, economical use of fissile material and many more. Perhaps the most important was the heater problem and although considerable progress has been made, it is still one of the major worries of rig design. To avoid any hazard to the reactor and possible delays to the reactor program, great care had to be taken with the safety of the rigs and the designs tended to be more complicated, the external shape becoming rather like a fast torpedo, the shaped ends of which eased insertion and removal from the reactor. Several features of these earlier rigs have been retained in the modern designs. These include sodium filling for heat transfer, double containment of fissile material and sodium and the use of mineral insulated cable for both thermocouple and power leads. The choice of sodium for heat transfer was made arbitrarily but with experience, this is felt to have been correct. The only other reasonable material that could be used is Sodium-Potassium alloy, NaK, as used in the USA. Although molten at room temperatures and, therefore, somewhat easier to handle than sodium (which has to be heated to about 150°C for handling) it is chemically more reactive and its thermal conductivity is about three times worse than sodium. Therefore, thermocouple readings taken from a point in the liquid metal filled cans are liable to a considerably worse error than if sodium only were used. This is extremely important especially when dealing with specimen surface heat ratings of some 200 W/cm².

A series of capsules similar to the first designs were irradiated each containing similar foils of uranium at

temperatures ranging from 400°C to 800°C but in most of the capsules trouble was experienced with both heaters, thermocouples and connexions. All the samples exhibited very serious 'coking' (Fig. 4) and were very friable.

The most successful of the early experiments was work on the growth of uranium under irradiation and consisted in irradiating two separate batches of pseudo single crystals of natural uranium. The experiment aimed at studying the growth mechanism of irradiation growth, one batch being irradiated at 500°C and the other at 200°C. These latter samples were contained in an aluminium block in a standard isotope element can and irradiated in a standard isotope channel in the reactor so that their temperature closely approximated to that of the coolant air. The other batch was contained in a graphite former sealed into a silica capsule around which a nichrome furnace was wound (Fig. 5). This was irradiated in a 2 in. dia. vertical experimental hole for some 8 months at 500°C during which time the furnace worked excellently.

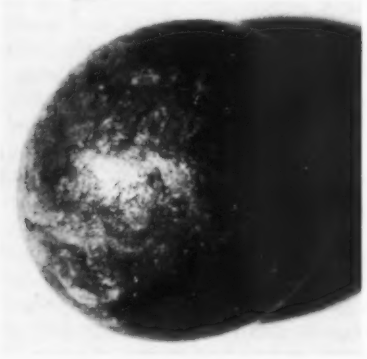
## INCREASED PROGRAMME

It had been the practice to irradiate not more than two samples side by side in the same capsule but to meet the increased programme it was decided to irradiate eight specimens in each 4-in. experimental hole. For convenience, the specimens were grouped in two batches of four so that if failure in one batch took place, then not all the specimens would be lost. A specification for the new rigs which were necessary is as follows:

1. Each rig to be capable of independent removal.
2. Each rig to contain four specimens.
3. Capsules to be contained in sodium in a stainless steel can.
4. A barrier of zirconium to be maintained between the can and the specimen.
5. Double capsules to be used to avoid risk of fission product or sodium escape should an inner can fail.
6. All specimens to be temperature controlled.
7. Two thermocouples to be used for each specimen; one for the direct control of temperature; the other to provide an overriding control should the temperature of the rig get too high.
8. Life of the rigs in reactor to be some 6 to 8 months.

(In general terms this specification has much in common with that used for present day designs).

The earlier experiments had shown that the foil experiments suffered very severe damage (see Fig. 4), possibly



Photograph of a typical unirradiated pellet (Fig. 6)

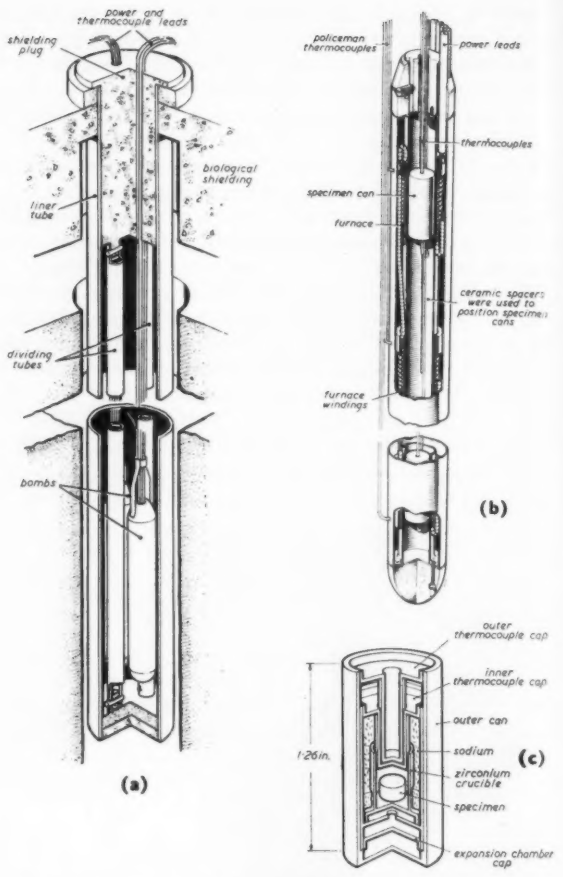



Illustration of the liners and rigs originally devised for Windscale (a); design of the first rig (b); details of the canning assembly (c) (Fig. 7)

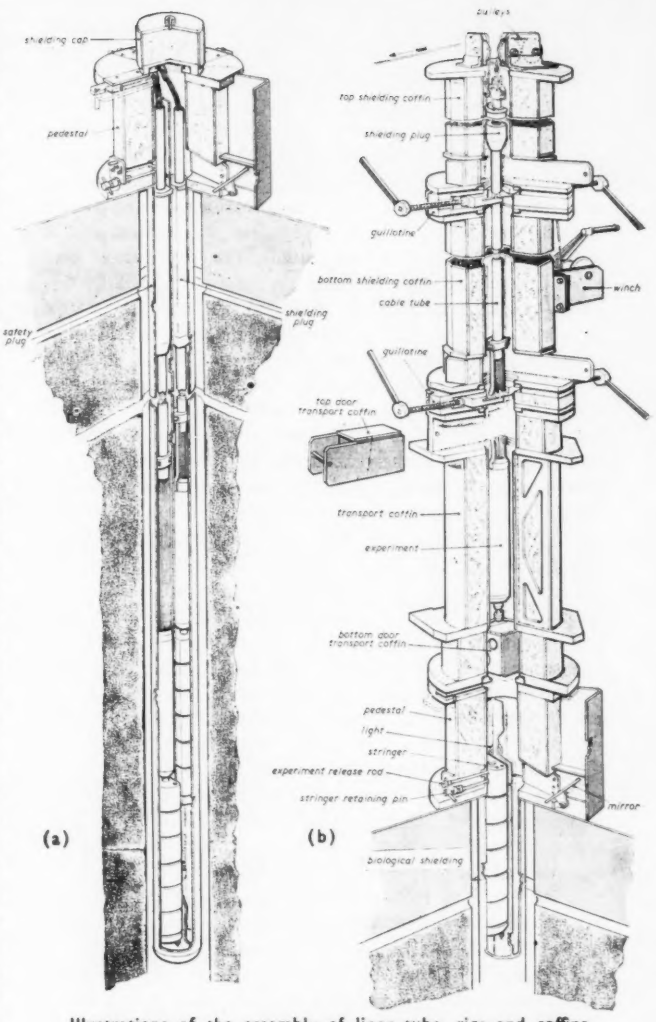
caused by the grain size of the metal approaching the thickness of the samples so that anisotropic effects would be marked. Because of this, the samples were produced as buttons (see Fig 6) although this was only done after it was found almost impossible to produce cylinders of small size by arc casting. The final sample size chosen was approximately 0·1 in. dia. × 0·1 in. high.

At the same time, the sample enrichment was chosen so that the ratio of flux on the surface to flux in the centre was 60%.

The first rigs to this new specification are shown diagrammatically in Fig. 7*b* and the method of fitting into the reactor is illustrated in Fig. 7*a*. The rig was a long thin torpedo shaped container of 0·020 in. thick stainless steel fitted with shaped aluminium ends. Inside were fitted four nichrome furnaces wound in alumina beads on another thin stainless steel tube. These furnaces were independently controlled but to save space and reduce the number of power leads a common return was used. The ends of the furnaces were held in position by stainless steel clips and the ends of the nichrome windings brazed to copper cored mineral insulated cable which in turn was joined outside the rig to aluminium cored aluminium clad mineral insulated cable specially manufactured for the purpose. The use of aluminium considerably eased the problem of waste disposal of the cables. The jointing of these cables was

a serious problem and failed furnaces were frequently due to failure at the joint. The brazes inside the rig were another source of constant trouble as the slightest trace of flux left after brazing would cause severe corrosion in the reactor. The trouble was overcome by the use of high temperature brazes coupled with a very rigid inspection. The specimens were contained in small stainless steel capsules (see Fig. 7*c*) located one above the other with ceramic spacers between. Mineral insulated steel clad chromel/alumel thermocouples were used and were taken up past the higher capsules through the spacers, finally leaving the rig via a small aluminium plug. As can be seen from Fig. 7*a*, two of these rigs were inserted into one of the experimental holes in a staggered position. They were separated by a pair of aluminium tubes which terminated at the lower end in a flat aluminium plate and at the upper end were attached to the neutron shielding plug through which passed tubes carrying the power and thermocouple compensating cables. The first pair of these rigs worked fairly well in pile but difficulty was experienced when unloading. To remove them, a long flask to contain the active wires was borrowed from other work and a simple coffin to hold the rigs constructed, similar to that used for the earlier rigs. These were stacked, resting upon a stool over the top of the experimental hole and a small gap left between the top of the rig flask and the bottom of the cable flask to permit the cables to be sheared by bolt clippers after removal of the rig from the reactor. Briefly, the removal operation was as follows: after reactor shutdown, the shielding plug was withdrawn and the two aluminium tubes disconnected from the plug and clamped together at the top of the hole. As much of the wires as possible was cut away until their activity prevented any more being exposed and a clamp attached to the remainder. The flasks were stacked up and the rig withdrawn until the top of the rig just appeared in a mirror placed conveniently between the two flasks. The lower shutter was then closed, the cables sheared and the rig retained in the flask. This arrangement gave partial success but jamming occurred as the rig was just coming out of the top of the reactor hole. In principle, this apparatus was correct but it was obvious that steps had to be taken to prevent this trouble and special purpose equipment built. The main trouble seemed to be with the aluminium dividing tubes and this device needed drastic revision. At this point therefore, a design study was undertaken by the Harwell Design Office, the Engineer in charge being A. G. Ashburn.

Because the reactor was used for production, it was essential for shut down time to be minimized and, because the experimental work which took up about 40% of the available experimental holes was likely to cause delays to start up times, it was decided to design for unload and reload during reactor operation. Figure 8 shows the final overall design. The most important change made was in the shape of the rig casing which became oval instead of circular although the actual furnace arrangement was not modified. To accommodate two rigs side by side in the reactor thimble an aluminium liner with an integral web was designed but presented considerable trouble in production because of its shape and the tight tolerances required. It was impossible to produce it in the work hardened condition so that to provide extra strength an aluminium magnesium alloy was used. This gave some improvement but even so, the liner produced was very liable to distortion during handling which would have resulted in jamming of the rigs. To overcome this and avoid distortion whilst loading into the reactor, angle iron crates were fabricated; these were used both for transporting and inserting the liners into the reactor. The crate, complete with liner, was hoisted vertically and the liner carefully lowered into the reactor. Another innovation was the graphite stringer below the rig. This consisted of graphite segments each about 3 in. long formed into a string which carefully fitted very closely the shape of the half section of the liner. Its purpose was to act as a neutron shielding plug after the removal of a rig. It was attached to the rig by a quick release clip in an aluminium block so that as the rig was removed it could be readily detached and held in position ready to receive the next rig. Apart from the outside shape the new rig was almost identical with the earlier one but all the cables and wires were contained in an aluminium tube which supported the rig in the thimble via an aluminium yoke. This tube passed up through the liner and through the top shield plugs being held in position by a clamp.



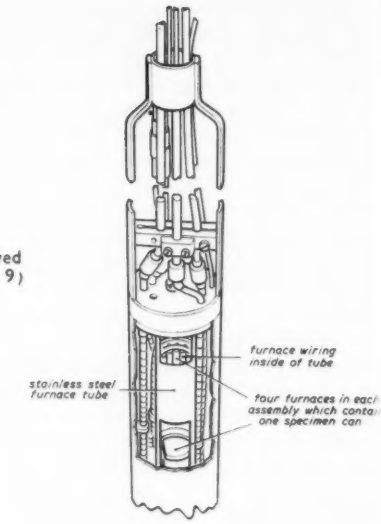

**Illustrations of the assembly of liner tube, rigs and coffins used with the pile running. (a) irradiation of experiment. (b) unloading (Fig. 8)**

From the top of the plug the wires and cables were taken across the top of the reactor to the control panels. The unload procedure with the reactor operating was as follows: The flasks (see Fig. 8) were assembled over the reactor thimble on a shielded stool and the rigs winched up. As the rig came close to the shield plug this lifted until the rig came clear of the reactor; at this point it was disconnected remotely from the graphite stringer and passed up into the coffin. The lower shutter was closed and a guillotine used to shear the cables. The top shutter was closed and the cable collected in the two top flasks between which was another guillotine to shear the cable into two sections. The process was reversed for loading a rig with the reactor operating except that the cable coffins were not used. When the apparatus was tried, the insertion of the inactive 'rig' was successfully carried out, but an attempt to remove this assembly when trouble developed with the thermocouples was unsuccessful.

Although considerable care was taken jamming occurred at various places in the liner tube and a position was reached where the rig had completely left the pile, but had not reached the uncoupling position. At this point the whole assembly jammed and could not be raised by loads judged to be safe. It was feared that excessive straining might cause the rig to break with the serious consequences of four canned irradiated specimens falling clear and reaching positions from which they could not readily be retrieved. Another unexpected feature of the operation was the considerably increased air count in the pile building, due it was thought to irradiated aluminium oxide or other material being scraped off the various components and being forced out of the liner by the piston action of the bomb and stringer. After removal of as much of the active cable as possible the jammed 'rig' was left to decay radioactively in the stool with the transport coffin in position until it could be removed completely.

Because of this trouble and subsequent examination of the apparatus it was decided to abandon 'rig' changes whilst the reactor was running although there is no doubt that the method could be perfected. This was a disappointing decision considering the amount of engineering effort that had gone into its design. The original method of putting rigs in or taking them out with the pile shut down was reverted to despite its disadvantages. Apart from the graphite stringer the remainder of the gear was retained and used until work at Windscale for the AERE experimental programme ceased.

As can be seen, the designs were becoming fairly sophisticated but more development was needed on the 'rig' itself. So far, a simple high-low power input temperature control system had been used in which manual setting of a variac pegged the maximum power input possible. This method also gave a measure of safety as it fixed the total possible heat input. As much of the heat required to maintain temperature resulted from fission heat generated in the specimens, serious thermal cycles occurred at reactor shutdowns and large scale reactor flux variations. Experimental requirements demanded better temperature control with a reduction and if possible, total elimination of these thermal cycles. Due to the oval shape, the outer casing of the rigs had been operating at temperatures approaching the safety limit of 500°C. At the same time the response sensitivity of the furnace was rather sluggish resulting in thermal cycling. The requirements, therefore, were for a new


furnace wiring inside of tube
stainless steel furnace tube
four furnaces in each assembly which contain one specimen can

Details of improved furnace design (Fig. 9)

furnace design with a quicker response time and better insulation for the outer casing; coupled with this, the control system needed revision in order to eliminate thermal cycles and provide proportional control over the whole range of reactor power. The resultant improved furnace design (see Fig. 9) was coupled with one of two proportional systems provided by either a Honeywell Brown Electronik system, or a Kent Mk 20 instrument. The latter used a pneumatic system to control a variac via a slave arm.

These new rigs and instruments control panel considerably eased the work of the reactor staff and were in continuous use until the Metallurgy divisions work at Windscale came to an end.

## SUMMARY

During the period under discussion disappointments and failures were common as heaters, thermocouples and other components gave considerable trouble and premature withdrawal from the reactor was sometimes necessary. In retrospect, steps taken to overcome these difficulties appear logical. A considerable quantity of scientific data was obtained and the problems likely to be met in the irradiation of fissile material became much more clearly defined.

Mention should be made perhaps of the difficult conditions under which this work was carried out. Apart from the constant pressure to carry out more and more experiments, work was always to a shut down date and, frequently, the rigs would be despatched to the reactors without the samples which would be taken up immediately before the rig loading. At Windscale because of pressure of standard reactor duties, help was limited and this meant that much of the work had to be carried out at night and between major reactor duties. In spite of this the excitement of this new type of work gripped the team and, on looking back, the most outstanding thing was perhaps the enthusiasm with which everyone worked and these remarks apply also to members of those other Groups i.e. Pile Operation Windscale, Pile Instruments Windscale, Design Office Harwell, Instruments Harwell, Transport Section, Harwell and many others without whose help the work could not have been carried out.

The Reactor Physics complex (left centre, striped roof) contains Nestor and the exponential hall; just behind are reactor halls 1 and 2 housing Nero, Helen and Zenith, and the road leads on to the Dragon site (top left)

# Research at Winfrith

*by J. SPENCER BURKETT, Assistant Editor,* NUCLEAR POWER

SINCE SITE construction started in September 1957, great strides have been made at the Atomic Energy Establishment at Winfrith Heath. With the exception of the Zebra and Dragon buildings most of the main construction work is completed.

A large effort is naturally centred on the development of the OEEC Dragon Project, but there is also an impressive range of physics and engineering research being undertaken—and scheduled—on behalf of the Magnox stations, advanced gas cooled reactors and high temperature reactors, in addition to investigations into water- and organic-moderated systems.

To obtain all the data required for reactor design purposes there is the need both for the relatively inexpensive sub-critical assemblies and zero energy reactors.

### Sub-critical assemblies

The first units to be set up at Winfrith, to investigate the reactor physics of the Magnox and advanced gas cooled reactors, were the four graphite assemblies transferred from Harwell, working on a joint effort with the main nuclear consortia known as BICEP, the British Industrial Collaborative Experimental Programme. The two exponential stacks, constructed of graphite bricks, have been designed to produce a wide range of lattice geometries (Fig. 1). Neutron distribution is measured with boron fluoride counters to arrive at critical size. More detailed information on the neutron behaviour in the components of reactor lattices are obtained from the two cold fine structure stacks which have higher neutron density.

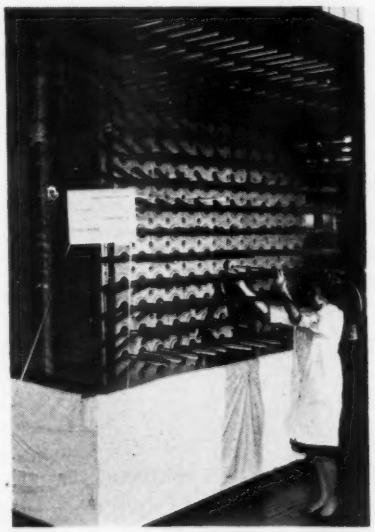
With the continued operation of the Magnox and advanced gas cooled reactors, plutonium is produced in the fuel elements and the reactor's characteristics change. To study these effects, two further assemblies have been recently commissioned, SCORPIO I and II (a diagram of Scorpio I is given on p 114 September). Since the effect of the plutonium is dependent on the temperature of the graphite moderator, the apparatus is designed to operate at temperatures up to 400°C, a range that will be encountered in practice.

The graphite stack of the fine structure experiment, SCORPIO II, forms a rectangular structure of 6 ft × 6 ft × 4 ft 8 in., the latter dimension being the length in the direction of the fuel channels (Figure 2). The stack is heated by radiation from electric heaters situated on the top and bottom faces and is cooled by nitrogen, in a closed circuit system, entering and leaving the stack chamber on the same faces as the heaters. The stack is enclosed in a primary containment and access to the central block of graphite is obtained through a sealed door. The stack chamber is installed inside a second containment, the personnel chamber, which also houses a preheat oven and cooling box. Flux measurements are made by measuring the activity of foils embedded in a central block of graphite inserted in the stack. This has to be cooled within one half-hour of completion of an experimental period, the cooling box operating with the same cooling circuit as the stack chamber, the full flow being diverted for this purpose.

*Experimental facilities are already operating; others are nearing completion, and a staff of some 2000 has been assembled, many from Harwell. Interchange of ideas and experimental results is extensively practised, not only between other Authority establishments, but also with industry and other countries.*

The use of graphite and beryllium as structural and fuel canning materials for the advanced gas-cooled reactor has made it necessary to study the local temperature variations that occur within the core lattice and their effect on the power level. For this purpose a differentially heated graphite assembly has been provided that consists of a graphite stack pierced by seven channels, six of which are radially disposed around a central channel (Figure 4). The outer channels are fitted with graphite liners and large beryllium tubes, whilst the centre channel is fitted with a graphite liner and a 37 beryllium tube cluster. Uniform heating of the graphite liners and beryllium tubes is achieved by passing through high amperage low voltage current, using four transformers.

The equipment is designed to provide for the temperature differential to be effective between the beryllium tube, the graphite liner, and the graphite stack, whilst maintaining the



A neutron counting chamber is being inserted into one of the two exponential stacks operating under Bicep (Fig. 1)

graphite stack at room temperature. The graphite liner is designed to be never more than 200° above the beryllium tube. The interposition of pure aluminium reflectors between all surfaces meets this requirement. Vickers-Armstrongs (South Marston) Ltd are responsible for the design of this facility and the two Scorpio assemblies.

Another sub-critical assembly, HELEN, which was commissioned in mid-summer, has been built in a form that will help to extend calculation methods for systems moderated by light water or organic liquids, and with fuels having some enrichment with either uranium 235 or plutonium (Figure 3). This experimental assembly consists of thin parallel plates of plutonium-aluminium alloy fuel suspended in a tank containing the chosen liquid moderator, the fuel assembly having a simple geometry to assist in comparison of experiment and theory. Neutron flux is measured automatically using remotely controlled fission chambers, at a number of pre-determined positions in the assembly.

**WINFRITH'S EXPERIMENTAL FACILITIES**

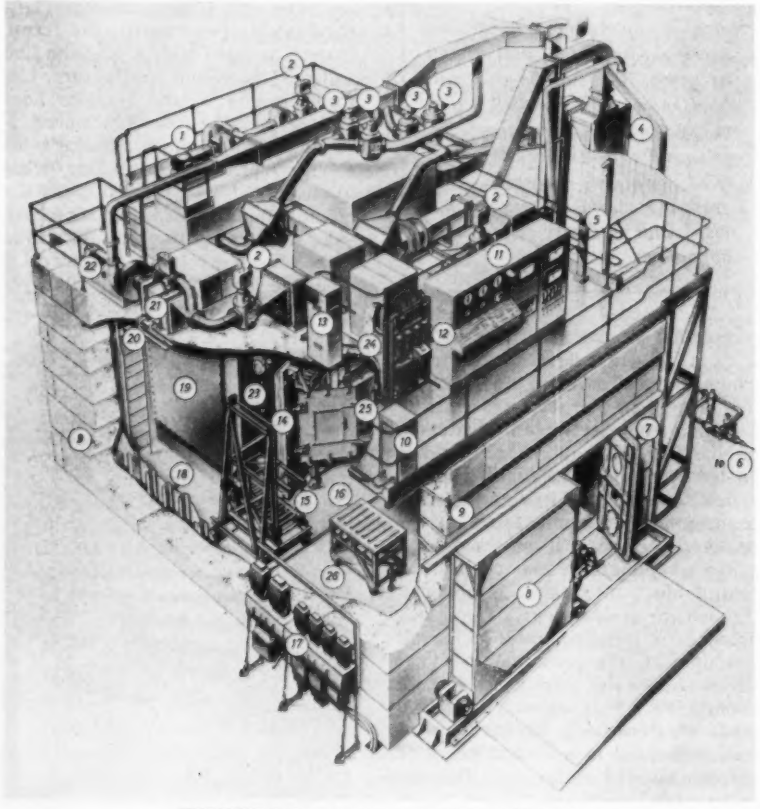
| **Reactors** | | **operating** |
|---|---|---|
| ZENITH | zero energy graphite moderated reactor | December 1959 |
| NERO | " " " moderated and oscillator reactor | December 1960 |
| NESTOR | 10 kW neutron source reactor | January 1961 |
| DIMPLE | zero energy liquid moderated reactor | 1961 |
| HECTOR | " " oscillator reactor | 1962 |
| ZEBRA | zero energy fast reactor | 1962 |
| DRAGON | HTGC reactor experiment (OEEC) | 1963 |
| **Sub-critical Assemblies** | | |
| BICEP | 2 exponential, 2 fine structure assemblies | September 1959 |
| SCORPIO I & SCORPIO II | graphite moderated assemblies; heated and contained exponential and fine structure | October 1960 |
| HELEN-1 | Liquid moderated experimental assembly | October 1960 |
| | Differentially heated graphite assembly 'B' | November 1960 |

## Zero energy reactors

For further studies on neutron behaviour in graphite systems, particularly with a view to improving theoretical methods in the design of advanced gas-cooled reactors, Winfrith is already equipped with the zero energy reactor NERO and by 1962 will have HECTOR in operation. NERO, which commenced operation in February 1957 at Harwell, was dismantled in October 1959 and re-erected at Winfrith. It is expected to go critical in January 1961. Graphite dimensions, lattice geometries, fuel elements and control rod locations within the core can be varied within very wide limits to reproduce the system under investigation. The experiments carried out in NERO are to determine critical sizes, the effectiveness of reflectors, the kinetics of power changes and the performance of control systems (Figure 5). Of particular interest is its application of the oscillator technique, pioneered by the UKAEA and first used on GLEEP, for the measurement of neutron cross-sections, using only small quantities of material.

In this approach, cross-sections are not expressed in a differential form as a function of energy but as reaction rates in formalized and characterizable neutron spectra. By oscillating samples in and out of a critical reactor on a constant time cycle, integral measurements can be made accurately and quickly. The resulting oscillations are analysed with an electronic Fourier analyser, and from the ratios of the first harmonic amplitude and the 'steady' power level for the sample and a known standard (e.g. a dilute solution of boron in $D_2O$), integral cross-sections may be compared. HECTOR has been designed expressly to facilitate the use of this technique.

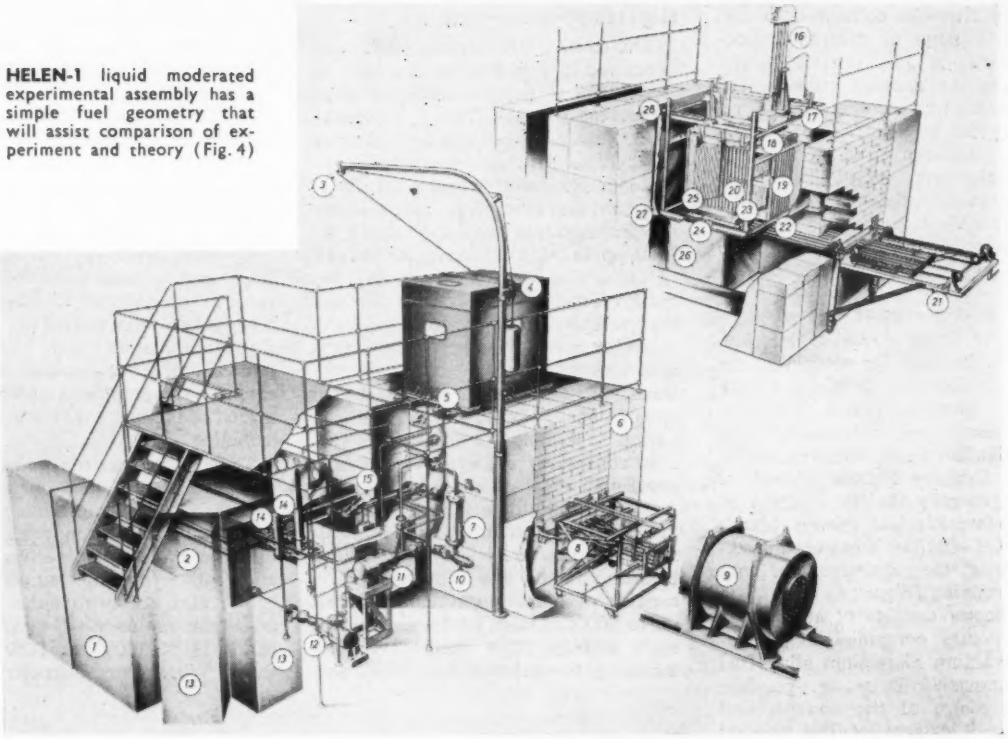
The main core, which is an annulus of graphite and highly enriched uranium/aluminium alloy plate, encloses a vertical hexagonal prism 4 ft A/F and 9 ft 4 in. high, that may be completely withdrawn from the reactor for modification. Various arrangements of fissile materials, absorbers and moderators may be used in this region which encircles the oscillator sample tube. This region may also be heated to 450°C by $CO_2$, a thermal insulation barrier isolating it from the main core. In addition to obtaining simple spectra of the Maxwellian plus slowing down



**SCORPIO 2** fine structure experiment (Fig. 2)

KEY: 1 differential pressure blower 2 containment shut off valves 3 relief valves 4 heat exchanger 5 cooling chamber valve controls 6 nitrogen reservoir 7 personnel door 8 shielding door 9 biological shielding 10 alpha monitor 11 control console 12 contactor panel 13 emergency lighting unit 14 stack chamber door 15 transfer trolley 16 working table 17 main switch board 18 alpha containment 19 stack chamber 20 emergency exit 21 alpha monitor gas cooler 22 personnel chamber blower 23 graphite stack 24 cooling chamber 25 pre-heat oven 26 personnel chamber 27 removable shielding 28 lead shielding for sources 29 source area graphite 30 source operating mechanism

**HELEN-1** liquid moderated experimental assembly has a simple fuel geometry that will assist comparison of experiment and theory (Fig. 4)



KEY: 1 control panels 2 dump tank 3 jib for concentrator 4 concentrator 5 connections to plutonium monitor 6 concrete shielding 7 ion exchange column 8 flexible source loading tubes 9 transport flask 10 ion exchange pump 11 draining pump 12 filling pump 13 plutonium monitor 14 filters 15 dump valve 16 scanner 17 vertical scan support beam 18 fuel security locking bar 19 fuel beam 20 fuel plates 21 source positioning unit 22 core support frame 23 beryllia blocks 24 antimony bars 25 beryllium cylinders 26 graphite reflector 27 core tank 28 corrosion specimen carrier

type, *ad hoc* experiments may be performed. For example, a section of a power reactor core at advanced burn-up may be built using irradiated fuel elements. Samples of irradiated materials may then be oscillated in spectra appropriate to the power reactor conditions, and this is of great assistance in studying long-term reactivity effects.

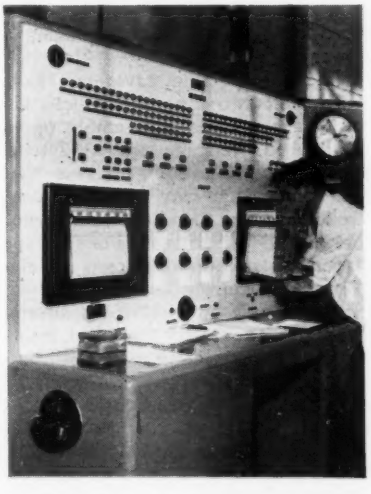
The high enrichment of the main core gives a small total core absorption and, consequently, a high reactivity change for a given cross-section of sample. The reactor is operated under a $CO_2$ atmosphere and is therefore insensitive to barometric pressure changes. The thermal barrier is of a split insulation 'guard ring' type in which heat losses from the central region are virtually eliminated, thereby giving very high temperature stability. It is desirable that the moderator temperature should not change by more than three-thousandths of a degree centigrade per minute, consequently mechanical stability will be achieved by the use of novel techniques, specialized materials and the highest standard of control and instrumentation.

Another reactor that is to be moved from Harwell to Winfrith in the early part of 1961, is the zero energy DIMPLE, the UK's first heavy water pile that commenced operation in 1954. Suitable for basic studies of liquid moderators it has also been used for experiments with the oscillator technique. The reactor consists essentially of a large aluminium tank filled with heavy water and surrounded by a graphite reflector and, with a power limited to 100 watts, only a minimum of shielding is required. It is a flexible tool, components do not become highly radioactive and it is possible to remove a lattice and replace another quickly.

### Fast reactor studies

Apart from the use of the Dounreay fast reactor experiment for investigating the system's potential for commercial application, further zero energy studies are necessary that will extend the earlier work carried out on ZEPHYR and ZEUS at Harwell. These studies will cover possible designs for a prototype power reactor. ZEBRA that is being constructed for commissioning in 1962, will enable investigations to be made covering a wide variety of fuel assemblies containing uranium and plutonium. The studies will fall into two stages, the first to gain an understanding of the basic neutron physics of dilute fast reactor systems, and the second for investigating problems closely associated with specific designs of power reactors.

The assemblies under study will be built up by loading fuel elements into a steel matrix of about 10 ft cubed.



Temperature and warning indicator board, complete with trip lights, for the differentially heated graphite assembly (Fig. 4)

The fuel elements contain both fuel plates and plates of neutron absorbing material of 2 in. square, thereby simulating the nuclear properties of the coolant and structural material required in such a reactor. The assembly will then consist of up to 300 nine feet long fuel cans. ZEBRA will be operated at room temperature and the heat output from the nuclear reactions in the core will be kept very low so that no cooling system is necessary.

### Neutron source reactor

A 10 kW graphite moderated reactor, NESTOR, due for completion by the end of the year, is intended as a powerful neutron source for subcritical assemblies that are built in five irradiation caves. Constructed by Hawker Siddeley Nuclear Power, it follows generally the basic design of JASON (see *Nuclear Power*, March 1959, pp. 90–91) but it has been modified to meet the requirement of continuous running (Figure 6).

The reactor consists of an annular core structure containing highly-enriched uranium aluminium alloy fuel plates immersed in water, graphite fills the centre of the annulus and surrounds it externally. The original Dido type loose plate fuel assemblies have been changed from 30 to 16 plate elements of half annulus width thus giving a double row of fuel element positions. To prevent corrosion between the graphite and core components, graphite blocks and wedges have been canned in aluminium. The control rod system, two safety, one fine and one coarse, have been slightly modified to reduce induced activation and radiation damage by encasing the sides and underneath with 2 in. of lead and ¼ in. of boral. Some of the gearbox and drive unit materials have also been changed to materials having a lower cross-section.

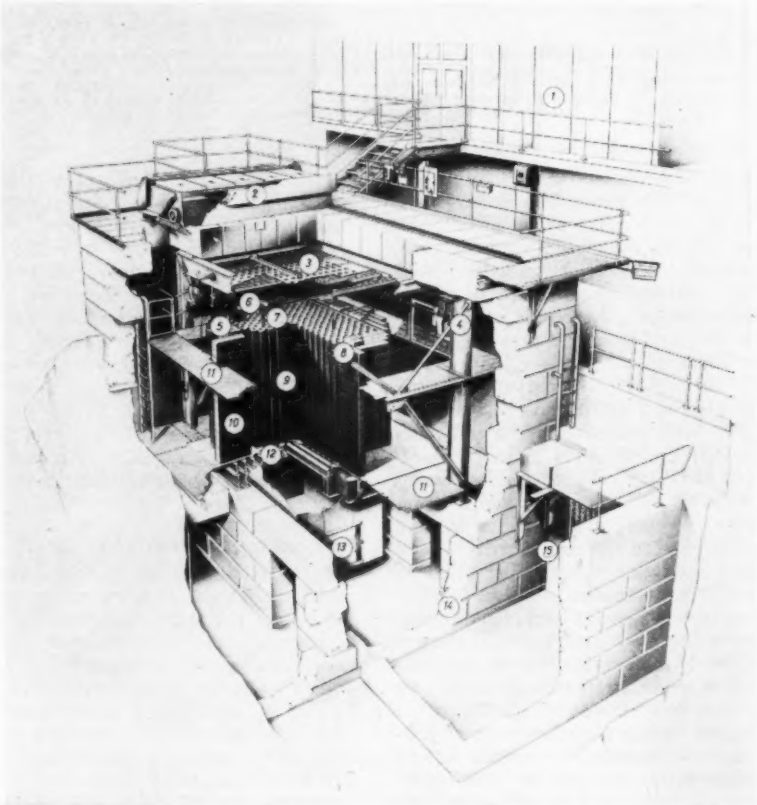
Each of the four caves that have been built into the structure can accept an experimental assembly up to 6 ft cubed, weighing up to 15 tons. The caves have been built so that neutron leakage can be strictly controlled and that there is no interference between the experiments. For foil type experiments requiring discrete irradiation times, neutron shuttering is provided consisting of polythene, lead and cadmium. The reactor top shield, incorporating the rotating plug, will initially be backed up by two layers of iron shot concrete beams of 3 ft thickness. The plug will later be replaced by an aluminium shield filled with bismuth to form a neutron window. Provision has been made for the addition of a small top cave capable of taking liquid moderated experiments up to four feet cubed.

### High temperature reactors

The DRAGON project, that was conceived in 1956 and handed over in April 1959 to a joint European team to become the OEEC High Temperature Reactor Project, has continued to make rapid progress, mainly on graphite development, temperature measurement and other important associated problems (see *Nuclear Power*, Feb. 1960, pp. 112–118). The reactor physics of the system is being investigated for the Project on the Authority's zero energy reactor ZENITH, which reached criticality in December 1959. Operating at a very low heat output, about 100 watts, the assembly is heated by a stream of hot nitrogen to the required operating temperature. The core consists of cylinders of graphite containing disks of enriched uranium oxide/aluminium oxide, graphite and thorium oxide. Neutron flux is measured by miniature pulse fission chambers designed by 20th Century that are capable of operating at temperatures up to 900°C. Other interesting instrument systems have been developed including the neutron flux decay analysers that measure reactivity when the reactor is in a sub-critical state, after a reactivity perturbation.

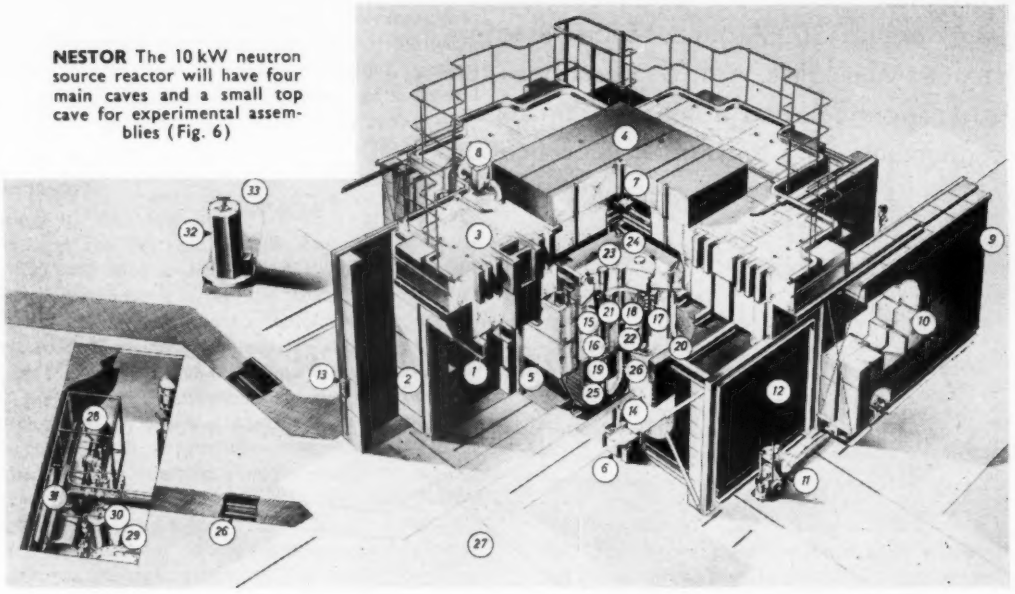
For the DRAGON Project, among the novel techniques being developed are those associated with graphite, particularly the development of suitable brazing techniques for joining graphite to both itself and other materials. The brazing techniques that have been developed are carried out under high vacuum conditions at pressures in the order of $10^{-5}$ mm Hg. The components to be brazed are placed in a vacuum chamber and, when the required degree of vacuum has been reached, the graphite components are heated to brazing temperature by R.F. induction heating.

The brazing material chosen is dependent upon the final operating conditions of the components; satisfactory joints have been made using a titanium cored copper-silver eutectic alloy at a brazing temperature of 950°C and also with either titanium or zirconium metal at brazing temperatures of 1800° or 1850° respectively. Where 2 in. diameter graphite



**NERO** zero energy reactor from Harwell will commence operation again soon (Fig. 5)

KEY: 1 control room 2 sliding roof door 3 fuel rod lattice plate 4 shut off rod motor 5 pulleys for raising shut off rods 6 pulley for fine control rod 7 shut off rod 8 fuel rod channel 9 graphite stack (adjustable lattice pitch) 10 graphite reflector 11 inspection galleries 12 bedplate and tiles (adjustable for lattice pitch variations) 13 safety tank to catch shut off rods 14 biological shield wall 15 fuel rod store



**NESTOR** The 10 kW neutron source reactor will have four main caves and a small top cave for experimental assemblies (Fig. 6)

KEY: 1 cave structure 2 cave wall 3 cave roof and access system 4 core roof 5 neutron shutters 6 corner shield pillar 7 neutron shutter mechanism 8 ventilation fan and filter 9 shield doors 10 recastable access plug 11 door/stack moving mechanism 12 graphite stack 13 neutron shutter controls 14 plinth 15 reflector 16 reactor outer vessel 17 control rods 18 central thermal column 19 $N_2$ sparge 20 ion chamber 21 reactor inner vessel 22 fuel box 23 rotating plug 24 top shield 25 lead shield 26 dump pipe 27 steel floor 28 dump tank 29 heat exchanger 30 ion exchange column 31 $N_2$ sparge bottles 32 fuel transfer flask 33 fuel storage holes

tubes are to be butt brazed, using a Radyne Model C400 40 kW heating assembly, this temperature has to be reached in ten seconds to flow zirconnium or vanadium jointing material between the tubes. The graphite is protected from oxidation by positioning it inside a silicon tube through which flows an inert gas.

Standard thermocouples cannot be used in the Dragon core since they will react with hot graphite and cannot withstand the intense level of irradiation. One alternative method that is being successfully developed is the use of ultrasonics, a system that is based upon the fact that the velocity of the sound waves varies with the temperature of the material. When sound waves are sent through a refractory material they are reflected from any joints or 'shoulders' in the material as well as from the end. In the system devised at Winfrith, a graphite rod with a shoulder cut in it at a suitable distance from the end is being used. A strong echo is received from both the end and the shoulder of the graphite specimen.

To obtain the velocity of a sound wave, the frequency is adjusted so that the echo of the first pulse of a pair is received from the end coincident with the echo of the second pulse from the shoulder, thus resulting in a strong combined signal. When the temperature of the specimen between the shoulder and the end changes, it is necessary to adjust the interval between the two pulses to obtain the strong combined signal. This change in frequency is then a measure of the temperature change.

## Engineering technology

In spite of the extensive activities in the US on boiling water and pressurized water reactors, the various phenomena associated with the formation of steam bubbles on heated surfaces and the flow of these bubbles in water are extremely complex and little understood. Work is done at Winfrith on basic heat transfer flow characteristics and void distributions of 2-phase mixtures together with a close study of the mechanism of burnout. Experiments will soon be started on collecting information on heat flux limits under transient conditions and on improving burnout flux level by centrifugal spinning flow.

Experimental data is also being obtained on the behaviour of polyphenyls at temperatures above 400°C. and under prolonged irradiation, particularly of the degree of breakdown. Heat transfer rig investigations include the study of the organic coolant at various stages of polymerization, upwards from 30%. Associated investigations are being made of the effect of the coolant on submersible pumps and their insulation.

## Control and instrumentation

New techniques and devices are being investigated for use in control instrumentation, one very promising line of research being the use of semiconductor materials. Reactor safety circuits using solid-state switching net works are under development that offer improved reliability, faster circuit response time and continuous checking of circuits without interrupting normal operation.

The properties of 'Zener' semiconductor diodes are being studied for the determination of their value for use in wide range neutron flux or health monitoring instruments.

Other investigations include those on radiation detectors for use inside advanced reactors, the development of flow measuring instruments that eliminate the conventional problems of streamlining or turbulent flow by using the effect of a flowing non-conductor on a magnetic field. This application can be used for liquids, particles in gases or gas in liquid flow.

Out-of-pile rigs are in use for the study of the effects of pressure and temperature on the mechanical stability of fuel element cans, and gauges have been developed for strain and thickness measurement.

## Computers

A wide range of problems are being calculated on the Mercury digital computer that has a storage capacity of 32,000 digits and a Pace analogue computer that has a particular application in the study of safety problems. Access is also available to Risley's IBM704 and AWRE's IBM7090.

There are about 30 Argonaut-type reactors in existence; this first article describes the approach to critical and some of the subsequent experiments on a British built modification

# *Jason operating experience—I*

*by B. W. EMMERSON, Grad.I.E.E., Reactor Supervisor, Hawker Siddeley Nuclear Power Co. Ltd*

THE HAWKER SIDDELEY Nuclear Power Co's research reactor Jason, based on the US ANL Argonaut, went critical last year and since the successful first run considerable experience of the original Argonaut core, and of a modified core, has been obtained. The general design characteristics of the Argonaut type reactor have been treated elsewhere (*1*) but the Langley Jason incorporates some modifications and is operated at 10 kW. In addition, current Jason designs range from 10 W to 100 kW. A detailed description of the Langley Jason is given in *Atompraxis* (*2*).

## Annular core

A weakness encountered with the original Argonaut design using 6 in. × 3 in. graphite blocks and fuel boxes with graphite spacing wedges was the lack of positive location of the fuel boxes, both radially and circumferentially, in the annulus. It was found that when a fuel box was removed from the core and then replaced into the original position, it resulted in a measurable change in reactivity. The use of oversize blocks or tapered wedges to lock the core into a tight condition made fuel handling and fuel relocation even more difficult. The redesigned aluminium fuel boxes are 3 in. square and accommodate 16 fuel plates per box when fully loaded. Removal of the fuel box top allows the fuel plates to be loaded into the box. A nose cone is fitted to the bottom of the fuel box for locating into an aluminium lattice plate. The graphite blocks for the core area have the same overall shape and dimensions as the fuel boxes. The fuel boxes and graphite blocks are positioned around the annulus by means of the graphite spacing wedges, the tops of which are fixed to the side of the outer core tank. All the graphite core components are coated with an epoxy resin to eliminate any absorption of water. This design has been in use since April 1960 and given most satisfying results, with no measurable change in reactivity after disturbance of the core components.

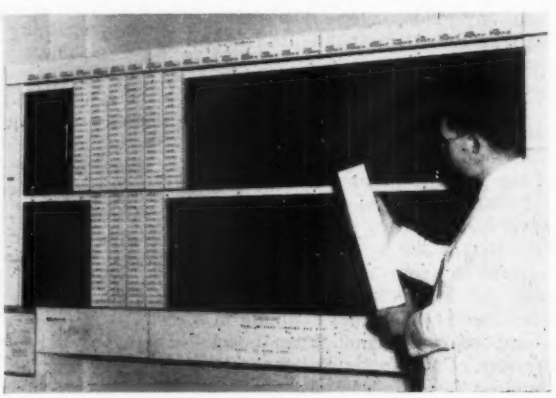
## Fuel handling equipment

A shielded flask is used for transferring fuel elements from the reactor to the fuel storage pits. The flask locates a fuel grapple which enables fuel to be drawn into the flask remotely. The fuel handling equipment itself has been designed to handle fuel that has been irradiated at 10 kW continuously for an infinite period with a cooling time of 24 h before handling. The thickness of the top shield box and density of the concrete filling have been increased to maintain a safe radiation dose rate while removing irradiated fuel boxes from the reactor and the central plug of the top shield box has been mounted on rollers to facilitate indexing over the required fuel box position.

Design modifications have also been made to the control rod mechanisms and the heat exchanger water cooling circuit as well as to the source drive mechanism; the source is now introduced into the mid-height region of the core through the bulk shielding, instead of beneath the core tank, as in the original Argonaut design.

## Shielding

The bulk shielding is of block construction and consists in the main of two layers of Barytes concrete approxi-



Section of the fuel tally board showing fuel box indicators being placed into the reactor core section (Fig. 1)

mately 240 lb/ft³ and two to three layers of normal concrete approx. 156 lb/ft³. All blocks were constructed using precision moulds, the concrete being vibration packed to obtain the maximum density. The dose rate measured at the face of the bulk shielding at 10 kW is in the order of 0·1 mpl.

### Instrumentation

To bring it into line with UKAEA practice the instrumentation has been redesigned. The start-up pulse counting channel uses a $BF_3$ detector and covers the operation of the reactor from the shut-down, neutron source removed condition, up to the moderator normal condition. A transistorized multirange linear channel is used to obtain detailed flux coverage over the working range of the reactor, from subcritical to full power. A 6 decade Log Power Channel covers the working range of the reactor as well as providing neutron flux doubling time information. In addition a single shut-down channel is provided which will automatically trip the reactor should the power exceed a preset value. Health monitoring is provided by means of two independent gamma monitors situated at strategic points of the reactor building. The conventional safety circuits are provided by means of shielding interlocks and instrument trips designed on a 'fail safe' principle.

### Acceptance tests

When the mechanical construction of the reactor is completed, certain acceptance tests must be carried out as part of the initial approach to critical programme. These include the testing of all instrumentation channels, the leak testing of the moderator and heat exchanger circuit and the functional testing of all mechanical components.

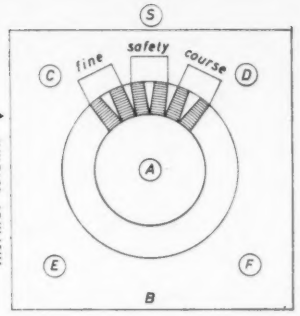
The initial approach to critical in September 1959, was made using the original Argonaut core design, the graphite blocks being 6 in. × 3 in. with similar size aluminium fuel boxes having a capacity for 30 fuel plates. Fuel plates for the Langley Jason are standard Dido type, but without curvature across the plate, containing about 11·5 g of U-235 with an enrichment of 80%.

### Fuel control

To maintain rigid control over the 200 fuel plates, a tally board system has been introduced (Fig. 1). The method is also being used at RCN (see *Worldview*, this month). Each fuel plate has a tag-card showing the serial number of the plate and its weight in U-235. Remington Rand 'graphtex' board, used to display the cards, is divided into a fuel core and a fuel storage section. Strips of graphtex are used to denote the fuel boxes and enable the position of the fuel plate in a fuel box to be readily shown. This tally board is kept current for all fuel changes and fuel box re-positioning and enables staff to see at a glance, the fuel conditions appertaining in the reactor, reactor building and fuel store at any time. When a fuel modification is made, the tally board is immediately brought up to date and photographed. The photograph is then kept as part of the fuel records.

### Approach to critical

In carrying out the initial approach to critical of the Langley Jason reactor, the following conditions were applied.




Detector positions for approach to critical and low power operations (Fig. 2)

| POSITION | DETECTOR | FUNCTION | CALCULATED FLUX RATIO*, $\phi_x/\phi_{core}$ |
|---|---|---|---|
| B (top) | $BF_3$ | sub-critical channel | 0·016 |
| C (centre) | RC6 | linear channel | 0·7 |
| D ,, | RC6 | log channel | 0·4 |
| E ,, | $BF_3$ | sub-critical channel | 0·045 |
| F ,, | RC2 | shut down channel | 0·03 |
| G ,, | $BF_3$ | start-up channel | 0·05 |

*applicable only when water is up

1. The ultimate core to be assembled was a single slab with fuel boxes placed symmetrically about the safety rod centre. From experience it was expected that a total of six fuel boxes would be required to achieve criticality, i.e. about 2000 g U-235. Six graphite blocks were, therefore, removed as required from the core in this area.

2. The reactor was checked out before loading the fuel to ensure that all instrumentation, interlocks and shut down equipment was functioning correctly.

3. Inverse count rate data was obtained from three $BF_3$ counters placed in convenient positions about the reactor, one on the reflector, one on the top of the reflector symmetrical with the core and the third in the external thermal column (see Fig. 2). Subsequent experience has shown that position *A* is preferable to *B* for the counter on top of the reflector.

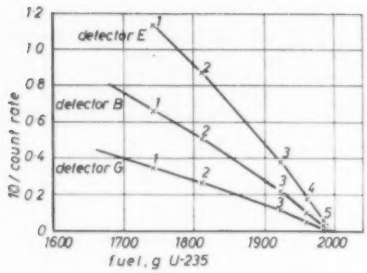
4. Inverse count rate versus U-235 mass was plotted for each detector to enable an estimate to be made of the critical mass. Such plots were made for:
   (*a*) coarse and fine control rods 'in'
   (*b*) coarse control rod fully 'out', fine control rod 'in'
   (*c*) coarse and fine control rods fully 'out'.

5. The first fuel addition was two full fuel boxes totalling 700 g of U-235. This is well below the minimum calculated critical mass of 1350 g. Two adjacent graphite blocks were removed from symmetrical positions about the safety rod centre line and the fuel boxes inserted.

6. The second fuel addition of two half filled boxes containing 174 g of U-235/box was symmetrically placed about the first two boxes, making a total loading of 1048 g. The fuel in the boxes was located at the outer region of the annulus to ensure that maximum control rod worth was obtained.

7. The third fuel addition was made by replacing the half loaded fuel boxes with fully loaded ones, giving a total U-235 mass of 1390 g.

8. From an estimate of the change of inverse multiplication per gramme made from the previous results an estimate was made of the next fuel addition. The criterion adopted was to load one half of the quantity estimated for criticality unless the shape of the curve indicated that a smaller addition was desirable. A maximum addition of 300 g/loading was also imposed.




The inverse count rate approach curve with the control rods out (Fig. 3)

9. The method described in (8) was repeated until an addition of fuel worth less than the fine rod worth (as estimated from the inverse count rate curves), would cause the reactor to go critical. This amount of fuel was then added and the reactor brought critical with a small excess reactivity.

10. A total of 10 fuel increments were made, including the first three 'lump' loadings, to achieve criticality. The final critical mass was in the order of 1980 g U-235 and the final loaded mass was 1998·19 g. This resulted in a nett excess reactivity of 0·23%. The inverse count rate curve obtained for the 'rods out' condition is shown in Fig. 3.

11. By referring to the inverse count rate curves for the control rods 'in' and control rods 'out' conditions, it is possible to evaluate the fuel worth of the fine control rod. Thus, as an extra precaution when making the final critical loading, this fuel worth would not be exceeded, so that insertion of the fine control rod would be sufficient to shut down the reactor.

### Approach with modified core

In April 1960, the original Jason core was modified to take the 3 in. × 3 in. fuel boxes with similar sized graphite blocks. In this instance, the fuel boxes had a capacity for 16 fuel plates. The approach to critical was carried out in a similar manner to the original approach except that the initial fuel loading was 1481 g U-235 with a second fixed loading of 1661 g U-235. This reduced the number of loading increments to six, giving a critical mass of about 2060 g U-235. Under this condition the core had a symmetrical loading. By replacing one of the partly filled fuel boxes located at the edge of the core against the thermal column, with a graphite block, and adding further fuel plates into the symmetrical box position at the other end of the core, the critical mass was reduced to about 1970 g U-235. Final adjustment to the critical mass was made by altering the plate positions (and spacing) within this end box. The total fuel mass for this core with an excess reactivity of about 0·4% is in the order of 1990 g.

### Reactor operating tests

On completion of a new core, certain acceptance tests must be performed on the reactor to check the satisfactory operating characteristics. The three major characteristics measured are: control rod worth, void coefficient, and temperature coefficient.

### Control rod worth

When a new core has been constructed or a modification to fuel location is made on an existing core, it is necessary to calibrate the control rods. Two control rod characteristics are normally measured, namely 'integral worth' and 'differential worth'. The former is a measure of the total reactivity worth of the rod for any given amount of rod insertion, whilst the latter gives a measurement of the reactivity worth per unit of displacement, for a small displacement of the rod at any position, i.e. its dynamic characteristic. The integral control rod curve is the more useful and is especially valuable for determining any change in reactivity when an experiment has been inserted into the core.

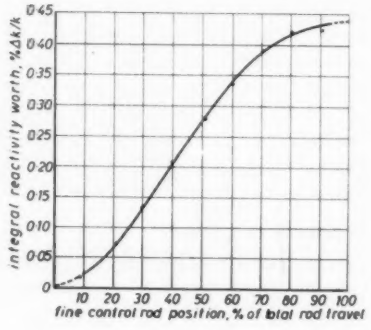
The control rod worth curves are obtained by making use of the curves calculated by Argonne National Laboratories relating flux ratio $\phi_t/\phi_o$ with negative reactivity ($\rho$) where: $t$ is in seconds, $\rho$ is in dollars, $\phi_o$ is the steady flux with the reactor critical, measured at $t = o$, and $\phi_t$ is the value of flux measured $t$ seconds after a step insertion of negative reactivity. Details of the calculation of these curves are given in various ANL publications (3).

### Integral control rod worth

Integral control rod worth can be estimated using either a positive or negative step change in reactivity, but from a practical as well as a safety aspect, a negative step is to be preferred. The control rod mechanisms are designed such that by removing the clutch voltage on any individual control rod mechanism, the cadmium absorber will fall into the core area, both under gravity as well as spring assistance. The time for inserting the rod from its minimum to its maximum worth position is in the order of 300 ms. A chart recorder is attached to the linear flux measuring channel and, provided the measuring and recording system is truly linear the ratio $\phi_t/\phi_o$ may be obtained directly from the recorder chart. From this ratio the value of reactivity inserted may be obtained by reference to the curves relating flux ratio to negative reactivity for various values of $t$. The method of measurement is as follows.

1. The control rod to be measured is withdrawn to its minimum worth position, i.e. 'rod out', and the reactor made critical on the remaining control rod. The linear ion chamber channel is designed to cover six flux decades by means of a decade range switch and it is necessary to choose a flux value which will give a recorder reading on the upper end of the range chosen in order to eliminate range changing when the flux decay is being measured.

2. The flux at critical should be sufficient to maintain a steady condition with the start-up source in its minimum contributing position, and to ensure that any gamma flux contribution from previous runs is swamped.




Integral reactivity worth of the Jason fine control rod calibrated by the rod drop method (Fig. 4)

3. The rod is dropped into the core by means of a 'rod drop' button which removes the voltage from the appropriate control rod clutch. Time markers are made on the recorder chart of the flux decay curve at various values of time ($t$) after dropping the rod.

4. The flux decay is recorded for at least 75 s after the rod drop, in which time it may fall by a factor of 10 on its original value $\phi_o$ depending on the reactivity involved.

5. The ratio $\phi_t/\phi_o$ is determined from the recording at the various values of $t$ chosen, as described in (3).

6. From the curve relating $\phi_t/\phi_o$ to negative reactivity ($\rho$) the value of negative reactivity is determined for each value of $t$.

7. Some allowance must be made after $t = 0$ for the effect of transients before calculating the steady flux decay. From experience this time may be of the order 10 s (*4*).

8. For a steady decay condition, the value of negative reactivity obtained from the flux ratio versus time curve, should be a constant for the given rod drop parameter, i.e. with the reactor critical and the control rod dropped from its 'out' to its fully 'in' position, one value of negative reactivity should be obtained (allowing for transient decay) this value being the overall worth of the control rod under test.

9. The above steps 1–8 are repeated, the control rod under test being withdrawn to various intermediate positions between fully 'out' and fully 'in'. The reactor is made critical and the rod dropped into the fully 'in' position for each individual measurement.

10. From the results of these measurements a curve may be drawn showing the potential reactivity worth of the rod for any given control rod position. Such a curve is shown in Fig. 4.

## Differential control rod worth

The differential control rod worth curve is obtained by making successive measurements of the positive period obtained for a series of small control rod withdrawals.

1. The reactor is made critical with the rod to be calibrated fully inserted.

2. The rod to be calibrated is withdrawn some 5% of its total travel.

3. By recording the output of the linear channel amplifier (as detailed for the integral rod worth measurements) the resultant stable flux doubling time associated with the particular control rod withdrawal can be obtained. Care must be taken to ensure that the effects of the initial transient periods have decayed before attempting to extract information from the recording.

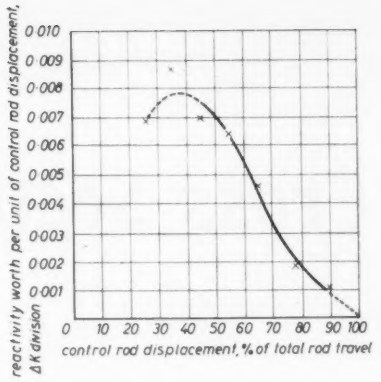
4. By dividing the recorded doubling time by Ln 2 the associated period can be calculated.

5. A curve relating 'positive reactivity to positive asymptotic period' is then used to determine the increase in reactivity introduced by the rod withdrawal.

6. The reactor is made critical by withdrawing the other control rod, ensuring that the position of the rod to be calibrated is not altered.

7. The rod to be calibrated is withdrawn a further 5% and the above procedure is repeated.

8. Using this method, points may be plotted giving the reactivity worth of the control rod per unit displacement for the various control rod positions. This is the differential reactivity worth curve. To obtain sufficient accuracy, the points of measurement should be fairly closely spaced, preferably not more than 2½% intervals. However, with increments of this amount the resultant positive period is so small that considerable time is required to obtain an accurate measurement (*4*). Rather than use small increments it is more convenient to overlap the various regions of control rod travel for successive period measurements. Thus, if the first period measurement is carried out for a rod increment from 0 to 5% of its travel then the second period measurement should be carried out for an increment of 2½% to 7½% of the rod travel, the third period measurement from 5% to 10% of the rod travel and the fourth from 7½% to 12½% of the rod travel, etc. The curve so obtained will give a measure of the change in rod worth per unit of displacement. Such a curve is shown in Fig. 5.




Differential reactivity worth of the Jason fine control rod (Fig. 5)

## Measurement of excess reactivity

When the integral control rod curves have been obtained, it is possible to measure the potential excess reactivity of the system for the particular fuel loading. The potential excess reactivity of the system is defined as the amount of reactivity being absorbed by those sections of control elements still inserted into the reactor when it is critical. If an integral rod worth curve is available for each of the control rods not fully withdrawn from the system, the potential excess reactivity can be estimated from these curves by noting the rod positions for criticality and reading off the amount of reactivity being held down by the percentage of control rod still inserted.

Where only a small amount of potential excess reactivity is present, it is possible to determine the amount by means of a positive period measurement with all control rods withdrawn. The stable positive period is measured and the associated reactivity is obtained from the curve relating 'positive reactivity' and 'positive asymptotic period'. This method is somewhat limited in that the safety circuits place a limit on the degree of positive period allowable, and any period shorter than this would result in a reactor scram. With the Langley Jason, this value is about 30 s.


**References**

1. Armstrong, R. H., and Kelber, C. N., *Nucleonics*, 1957, **15**, (3), 62–65.
2. Baines, B. D., *Atompraxis*, 1960, July.
3. Kinsel, W. R., *et al.*, *Nuclear Science and Engineering*, 1959, (3), 233–237.
4. Toppel, B. J. *ibid.*, 1959, (5), 88–98.

# Cross Section by GRACCHUS

IN ADDITION to finally deciding to give compensation for nuclear tenders, the CEGB has been doing some rethinking on its procedures for tenders and contracts for conventional power stations. I understand that the Board is now considering dividing each future conventional project between only two or three main contractors. This arises partly from their policy of building larger units, up to 2000 MW, and from their experience with turnkey contracts for nuclear stations, which has proved much better than expected.

THE PROPOSED English Electric-GEC merger, which took industry so much by surprise, may well prove to be the final straw for the United Power Company. I predict that this proposed child of the marriage between GEC and APC will find itself stillborn. This will be the second time that the two groups have found they are incompatible because of duplication of member companies activities. They agreed to come together late in 1959 but five months later decided against it. Early this year, it was announced that after further discussions, the two groups had agreed again to join forces. I expect to read another announcement soon about the merger.

THE THOROUGH behind the scenes work by the Organization for Economic Co-operation and Development's preparatory committee is expected to be completed during the winter

Their report will probably be signed in the middle of next year with ratification in the 12 months after that. The reorganization of the old OEEC looks like being very thorough and while the new body is not expected to alter the European Nuclear Energy Agency, the future of the European Productivity Agency may well be looked at very closely. Whether as a result of this re-organization, the United States will become a full member of ENEA is still not really known. The McKinney report advocates closer Western European and North American co-operation but one factor that may well cause the US to remain an associate member of ENEA is the problem of third party liability and safety, for American ideas differ from those held in Europe.

ONE OF THE most interesting articles in the first issue of 'Food Irradiation', the quarterly international newsletter published by the European Information Centre for Food Irradiation (see *Worldview*, September, p. 86), is that by Mr. Einar Saeland, deputy director of the European Nuclear Energy Agency. He points out that work is being started on studies on the technical and economic feasibility of food irradiation which will help set the groundwork for future activity. For certain products, of course, the radiation process has reached a stage where practical applications of the technique could be made. Mr Saeland's article observes that an ENEA special study group, for instance, has mentioned substerilization treatments such as sprout inhibition of potatoes and the elimination of salmonella in eggs as two possible projects.

The Newsletter itself, published in English and French, forms part of the wider activities of the Information Centre for Food Irradiation which was initiated and sponsored by the ENEA and the European Productivity Agency. This centre has been set up at Saclay for an initial period of two years with M. Pierre Leveque as Director and it is hoped that its work will encourage investigation and research and the industrialization of the results obtained. A useful first step has been taken in the Newsletter which, in addition to articles, contains a selected bibliography of food irradiation literature published during the last two years.

'ROCK 'N ROLL' is a phrase one hardly associates with nuclear marine propulsion though for any bad sailor the words convey a very real description of a ship's motion. And it is in this sense that 'Rock 'n Roll' is used to describe the Norwegian Institute for Atomenergi's studies of an experimental light water boiling water reactor which could be built in a floating sphere capable of imitating a ship's motion. Construction of the experiment is expected next year with the total cost estimated at $10 million. I believe the European Nuclear Energy Agency's information mission on nuclear ship propulsion recommends that this 'Rock 'n Roll' device be examined closely. Incidentally, this mission's report is due to be released shortly. It will be interesting to read what this four man team—of whom Professor J. Diamond of the University of Manchester was one—has to say after its study tour.

THE FINAL revised copy of Mr Robert McKinney's report 'Review of the International Policies and Programmes of the United States' is now generally available and has been received with interest though without the controversy that surrounded his tour through Europe and also his first draft. The report was originally to have been released in September but was delayed by over a month because of internal politics that made it necessary for part of the report to be rewritten. The original version was submitted to the Joint Committee on Atomic Energy on June 30 but apparently, I hear, aroused such feelings within the Committee itself that, after spending some time with the members, Mr McKinney rewrote part of the result of his year long survey but not before the report had reached the press. One of his recommendations that I thought most interesting was that the next international conference on civilian atomic power 'be specifically directed to broadening East-West technical relationships' and that it should be held in the Soviet Union in 1962 under the aegis of the International Atomic Energy Agency.

BROUGHT TO my attention this month was the attendance of Mr D. P. Ingamells of the Ministry of Transport at the recent meeting held in the US on organic moderated reactors between Dr W. E. Parkins of Atomics International and Dr H. S. Arms, English Electric, and E. E. Norton, chief of the Yarrow Admiralty Research Department. English Electric are associated with Atomics International in the development of the OMR and submitted a joint tender to the Ministry of Transport at the end of July for an OMR for tanker propulsion.

This device for the Dounreay fast reactor overcomes the problem posed by a sealed system

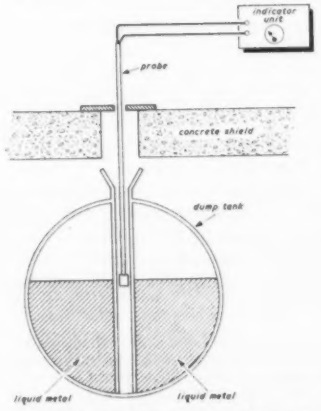
# Detecting liquid metal levels

*by A. STEAD, B.Eng. and F. G. LATHAM, Grad.I.E.E., UKAEA (Development and Engineering Group) Research and Development Branch, Capenhurst*

THE SODIUM-POTASSIUM coolant for the Dounreay fast reactor is contained in a sealed system made of stainless steel and instruments are needed in parts of this system to detect the presence of liquid metal. These measurements should preferably be made through the stainless-steel wall, to avoid weakening the wall or contaminating the instruments by liquid metal. Several principles could be applied, such as measurement of electrical resistance, the use of thermocouples, gamma-ray absorption and the inductive or eddy-current method. This last method was chosen as it is simple and can give the required accuracy. It has been used to design a dipstick and an instrument for defining fixed levels in a standpipe.

## Principle

If a conductor is brought near the windings of a transformer the inductance of the windings, and hence their mutual inductance, is reduced. Thus, if a constant alternating current is fed into the primary winding, the voltage across the secondary winding is reduced by nearby liquid metal. In practice, a balanced transformer system is used and only the change in secondary voltage is measured. The balanced arrangement has the advantage of compensating for the variation of zero reading with temperature, which occurs in the simple case because the depth of penetration and intensity of the induced currents depend on the resistivity of the stainless steel and liquid metal. Although this effect is negligible in the instruments described, it is important if a high resolution over the length of the transformer is required.

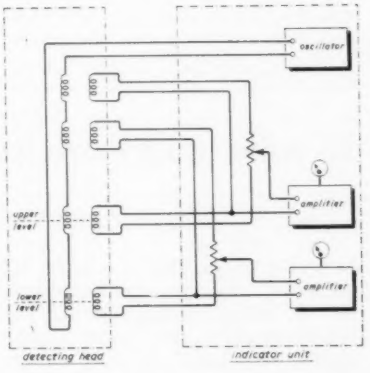



Dipstick for dump tank (Fig. 1)

The depth of penetration of the induced currents varies inversely as the square root of the frequency. At too high a frequency the induced currents are confined to the stainless-steel walls, and at low frequencies the sensitivity becomes low because a small secondary voltage is obtained for a given primary current. The working frequency, usually about 10 kc/s, is chosen by experiment, but is not critical.

## Dipstick for liquid-metal dump tanks

The purpose of this instrument is to measure the level in the dump tanks to an accuracy of $\pm 1$ in. This is only an occasional measurement and so a portable instrument of the dipstick type is adequate. This is shown in Fig. 1. A stainless-steel pipe of nominal bore 3 in. has been built into the dump tank to form a sealed pocket into which a detecting head can be inserted. The detecting head is made by mounting two transformers one above the other and this assembly is fitted to a graduated rod which can be lowered into the pocket. The primary coils of the transformers are fed with alternating current and the secondary coils are connected in opposition; hence, in the absence of liquid metal, the resultant secondary voltage is small. When the lower transformer reaches the level of the liquid, its secondary voltage changes and no longer balances that of the upper transformer. The out-of-balance voltage increases until the upper transformer reaches the liquid surface and balance is again approached when both transformers are below the level of the surface. The maximum out-of-balance voltage gives an indication that the plane separating the two transformers is level with the surface of the liquid.




Arrangement for defining two fixed levels (Fig. 2)

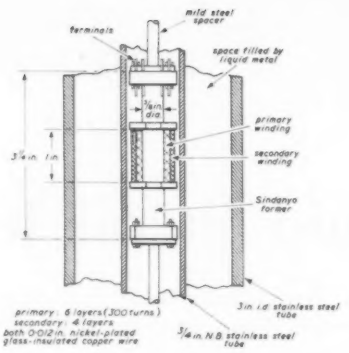
The temperature of the liquid metal may be high; hence the transformers are wound on a heat-resistant core and the wire used is nickel-plated copper insulated with silicone-impregnated glass fibre. The windings are in two slots, one immediately above the other. The feed and output leads are twisted pairs of Unipren cable; these are protected by the graduated rod, which is hollow and hinged to enable it to be used where headroom is low. The head unit is protected by a stainless-steel sheath. Because the instrument has to be portable, transistors are used in the indicator unit which consists of a feed oscillator and

an output amplifier, both of conventional design. The whole is powered by two 1½-volt dry cells. In operation, the head is lowered into the pocket until the amplifier output meter indicates the maximum reading. The depth of liquid is then read off on the graduations against the lip of the pocket, with an accuracy better than ± 1 in.

### Defining fixed levels in standpipes

In a variation of the method just described, the transformers are used to define two fixed levels in a standpipe. The readings are needed when the liquid-metal system of the reactor is being filled; the height of liquid metal in various standpipes depends on the flow conditions in the main system. At these positions it is necessary to know when a fixed lower level has been reached and also, for warning purposes, if a fixed upper level is reached.

The arrangement shown in Fig. 2 is used. Here the balancing halves of the two transformers are above the maximum level that the liquid metal reaches in the standpipe.




Details of transformer for level detector (Fig. 3)

The four transformers are identical; details are given in Fig. 3. Detecting heads containing the four transformers in stainless-steel sheaths are fitted into the standpipes, where required, and a portabe, battery-operated indicator unit using transistors plugs into the detecting heads. Indication is by two meters, one for each level. The half-maximum reading is taken as defining the required level, and an accuracy of ± ½ in. is readily obtained.

### Other applications

The instruments described have been installed at Dounreay and are giving satisfactory service.

The method can be used to detect or measure levels of other highly conducting liquids, for example, mercury. The success of the method in the application described, however, depends on the stainless-steel container being non-magnetic and having a relatively high resistivity. For use with other conducting liquids, such as concentrated electrolytes, the principle could probably be applied in a similar way, but the nature of the container would have to be considered in relation to the conductivity of the liquid being measured.

**Acknowledgment**

This article is published by permission of Sir William Cook, Managing Director, and Dr H. Kronberger, Director of Research and Development, of the United Kingdom Atomic Energy Authority (Development and Engineering Group).

# A new code for reactor pressure plant

*Lloyds Register of Shipping issues revised recommendations, the first since 1957*

LLOYDS REGISTER of Shipping has published revised recommendations for the design, manufacture and testing of pressure vessels and components. The Land Division of the Society has been closely associated with the survey and inspection of pressure components at the Calder Hall and Chapelcross stations and at five of the civil stations. This work, together with the experience on prototype installations such as the AGR and the Dragon project, has led to the revisions. The last issue of recommendations was in 1957. The Society will review and supplement the recommendations as further experience is gained.

Pressure vessel components for nuclear service are grouped in four categories, ranging from pressure vessels and components which will contain radioactive materials and are subject to neutron irradiation, to emergency containment vessels. The recommendations take into account the need to contain radioactive materials, the effect of neutron irradiation on materials of construction and the problems of accessibility for inspection and maintenance during the life of the plant.

Pressure vessels in general are to be designed to the widely accepted Class 1 codes and special attention is to be given to producing clean designs eliminating notch effects. The design pressure is to exceed by at least 10% the maximum anticipated. The recommendations say that stress intensification factors at nozzles and other openings in the pressure shell are to be kept to a minimum and in consequence the use of doubling plates for reinforcement is not acceptable.

Wherever possible, weldments are to be designed to allow 100% radiography and the radiography technique applied is to be the optimum currently available as far as defect sensitivity is concerned. The Society recommends hydraulic pressure testing as the preferred method though this, in fact, has not been carried out so far except for the AGR. In cases where total or partial pneumatic testing has been approved, or where strain gauges are fitted, pressurization of the vessel should be arranged in suitable stages, progressively diminishing. Strain gauge readings are to be taken at each stage. Leak testing is to be carried out after pressure testing.

Tentative requirements are outlined for the design of containment vessels. The design is to be related primarily to a calculated pressure based on a major accident condition which, in general, should include the effects of failure of a main primary coolant duct, or a secondary coolant circuit, resulting in the discharge of either primary or secondary coolant to containment. The design must also consider a possible breach of containment by missile impact through failure of an internal component or a burn-through following a core melt-out. Generally, the containment vessels are to be designed and constructed according to Class 1 codes.

In each of the categories, recommendations cover materials, construction, fabrication, workmanship and testing. Those for fabrication include non-destructive examination, the weld procedure tests, welding operator tests, and production tests.

Appendices deal with requirements for over-pressure relief systems, ultrasonic examination of materials, plate pressing procedure and production tests, and weld procedure and operator tests.

Copies of the publication, *Survey of Pressure Components for Land Based Nuclear Installations—Provisional Requirements 1960*, are available from Lloyds Register of Shipping, Land Division, Norfolk House, Croydon, price three guineas.

# *Points from Papers*

*reports, meetings, conferences*

## INSPECTION AND TESTING

Because of radioactivity hazards the design, construction and testing of pressure components must be of the highest standard. The experience in this field gained by Lloyd's Register of Shipping was given in the first nominated lecture of the Institution of Mechanical Engineers. The paper deals with the problems associated with large size and site fabrication of the reactor pressure parts. Experience at Calder has shown that components on the heat exchanger side of the stop valve can be efficiently examined. The need to periodically inspect other circuit components is also emphasized. Reference was also made in the paper to need to improve leak tightness and the desirability of maintaining simplicity and and the inclusion of essentials only in new specifications and codes of practice.

The discussion highlighted some of the practical difficulties connected with the large size of the components. Increasing plate thickness of pressure vessels meant that radiography became more difficult. Linear accelerators were now being introduced and Mr P. T. Fletcher said that APC were experimenting with a 4·4 MeV one. Hydrostatic testing poses practical problems due to the great weight of water and economic ones; this type of testing could cost as much as 10% of the pressure vessel costs and all civil stations so far have been pneumatically tested. The temperature at which the tests should be carried out also was a point of controversy. Strength of weld metal in primary circuits was another problem, the difficulty of guaranteeing V-notch strength above 15 lb/in² at − 10°C was a figure quoted. In this connexion the plea was made by Mr K. J. Wooton for the standard to be based on a statistical average for a series of tests rather than rejection because of one low value.

*Inspection of primary circuits and reactor pressure vessels of nuclear power plant.* H. N. Pemberton and E. Crossley. Institution of Mechanical Engineers preprint 7/60.

## LEAK TESTS AT CALDER

The first reactors at Calder Hall showed a significant leakage of carbon dioxide and detailed testing was carried out on subsequent Calder Hall and Chapelcross reactors to trace and minimize this leakage.

Four techniques were used for detection. Soap tests, with the circuit under test pressurized, were able to detect leaks of less than 0·01 lb/day at a pressure of 100 lb/in². This was usually the first check made after plant assembly. With the plant pressurized, indication of leakage rate was given by measuring fall of pressure with time. This method does not give precise location of leaks and its sensitivity varies inversely with the volume of the plant. In conjunction with the soap test, however, it proved effective. An infra-red gas analyser was used with circuits pressurized with carbon dioxide instead of air. The sensitivity was about the same as that of the soap test but the method has its limitations where a number of identical joints need to be checked. Other methods were devised to measure total gas loss and regular leakage from particular points and the measurement of specific leaks aided the reduction of leakage for a given effort.

The conclusion reached in this paper is that the original high leakage at Calder was possibly due to slightly porous castings, undetected seal or butt welds, gas sampling pipe brazed coupling leaks, joint leaks, and fabricated plate defects. (See Tables 1 and 2.) Several sources of leakage have been found and the lowest leakage rate achieved during the final test is about 600 lb of air per 24 hours; 200 lb of this leakage has not been accounted for. These values are about half of those for Calder No. 2. The two potential sources of these unaccounted leaks are thought to be the gas circulators and the b.c.d. system. These were tested individually but were not completely covered in the full circuit test.

**TABLE 1** *Total leakage*

| | LEAKAGE, lb/day | | | | |
|---|---|---|---|---|---|
| | Calder 2 | Calder 3 | Calder 4 | Chapelcross 1 | Chapelcross 2 |
| Total air leakage indicated by loss of pressure | 2130 | 885 | 740 | 1000 | 600 |
| Loss by oil sampling | 23 | 17 | 17 | 17 | 17 |
| Measured leakage | 1240 | 115 | 316 | 270 | 335 |
| Leakage indicated by pressure loss tests on individual items | No tests | 175 | 52 | 33 | 36 |
| Air loss not located | 867 | 578 | 355 | 680 | 212 |
| Equivalent to hole diameter (coefficient of discharge 0·7), in. | 0·069 | 0·056 | 0·044 | 0·060 | 0·034 |

**TABLE 2** *Analysis of leaks*

| | LEAKAGE, lb/day | | | | |
|---|---|---|---|---|---|
| | Calder 2 | Calder 3 | Calder 4 | Chapelcross 1 | Chapelcross 2 |
| Relief valve seats | 573 | 40 | 132 | 1 | 16 |
| Other valve seats | 468 | 14 | 12 | 43 | 20 |
| Valve glands | 129 | 48 | 119 | 156 | 231 |
| Flanges, welds and similar joints | 54 | 13 | 53 | 21 | 47 |
| Others | 16 | — | — | 49 | 21 |
| Total | 1240 | 115 | 316 | 270 | 335 |

*Leak tests on Calder-type reactors.* J. K. Smith and J. Cheetham. Institution of Mechanical Engineers preprint 4/60.

## PULSE GENERATOR

This report describes a pulse generator using mercury-contact relays which provides an accurately known and stable output for use with pulse height analysers. Pulse generators of this type have been developed in North America and this new design incorporates improvements. The design philosophy and circuit theory is outlined, and an indication of further developments given.

*A precision relay pulse generator for use with pulse amplitude analysers.* M. O. Deighton. AERE Harwell. *Report AERE EL/R2717.* 21 pp. Available from HMSO 4*s*.

## LIQUID SCINTILLATORS

The authors of this report recommend that liquid scintillation coincidence counters should be used for the assay of beta activity in effluent from plants which handle radioactive materials in quantity and where this effluent is discharged into fresh water. The counter they describe uses 2,5-diphenylaxazole and naphthalene in dioxane and has been calibrated against $4\pi$-counted solutions of radioisotopes of different maximum beta energies.

*Liquid scintillation counting of aqueous samples.* B. A. Loveridge and A. M. Thomas. AERE Harwell. *Report AERE R2942.* 25 pp. Available from HMSO 4*s* 6*d*.

## RIVAL TO DIFFUSION THEORY

The work reported here is an attempt to obtain a relatively simple method of calculation which can replace diffusion theory in reactor survey calculations. The method considered is the solution of the one velocity Boltzmann equation for an isolated source in an infinite medium.

*Approximate solution of the one velocity neutron transport equation in an infinite medium.* G. Rowlands. AERE Harwell. *Report AERE R3369.* 28 pp. Available from HMSO 4*s* 6*d*.

# *New Reports*

*The oxidation and corrosion of zirconium and its alloys. (XI. The oxidation kinetics of zirconium-niobium binary alloys in steam at 300–500°C).* B. Cox, M. J. Davies and T. Johnston. AERE Harwell. *Report AERE R3257.* 28 pp. Available from HMSO 4*s* 6*d*.

*Measurement of the viscosity of Santonex 'R', para-, meta-, and ortho-terphenyl, diphenyl and Dowtherm 'A'.* R. W. Bowring, G. L. Christie and D. A. Garton. AERE Harwell. *Report AERE R3309.* Available from HMSO 8*s*.

*Strontium-90 in human diet in the United Kingdom 1959.* Agricultural Research Council Radiobiological Laboratory. *Report AGCRL 3.* 58 pp. Available from HMSO 3*s* 6*d*.

*The use of submillimetre waves for studying high density plasmas.* S. M. Hamberger. AERE Harwell. *Report AERE R3260.* 36 pp. Available from HMSO 6*s*.

*Photographic emulsion dosimetry and the AERE film dosimeter.* M. J. Heard, J. B. Cook and P. D. Holt. AERE Harwell *Report AERE R3300.* 46 pp. Available from HMSO 7*s*.

If high flux reactors are operated on a part-load basis considerable reactivity will have to be invested in xenon override

# Xenon poisoning during two shift operation

*by D. L. BOOTH, M.A., D.Phil., Atomic Power Division, English Electric Co. Ltd*

XENON CONCENTRATIONS during cyclic operation have been calculated by an electronic analogue computer, so as to obtain data required for the study of reactor performance under part-load conditions. Results obtained were for a wide range of load cycles and are applicable to reactors with peak fluxes up to approximately six times those in current designs of gas-cooled, uranium fuelled reactors. As the computations were in terms of generalized variables, the results are applicable to any reactor system with fluxes in the appropriate range.

*Two-shift operation provides an example of the need for xenon override. The demand for electricity is greatest during normal daylight working hours, and on weekdays. As more nuclear plant is commissioned some nuclear power stations may have to operate on a part-load basis. It follows that there will be an increase in peak xenon concentration in these reactors. The effects of this increase will be greatest in reactors with high neutron fluxes.*

## Method of simulation

The equations for the concentrations of I-135 and Xe-135 at a point in the fuel of a reactor are

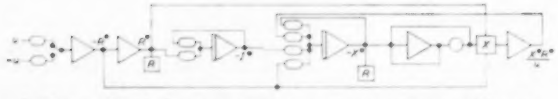
$$\frac{dI}{dt} = \gamma_I \Sigma_f \phi - \lambda_I I \qquad (1)$$

$$\frac{dX}{dt} = \lambda_I I + \gamma_X \Sigma_f \phi - \lambda_X X - \sigma_X X \phi$$

if the tellurium stage and capture in I-135 are neglected.

**NOTATION**

| | |
|---|---|
| $I, X$ | concentrations of I-135 and Xe-135 per unit volume of fuel |
| $\gamma_I, \gamma_X$ | yields of I-135 and Xe-135 as direct fission products |
| $\lambda_I$ | 2·073 $10^{-5}$/s, decay constant of I-135 |
| $\lambda_X$ | 2·874 $10^{-5}$/s, decay constant of Xe-135 |
| $\Sigma_f$ | macroscopic total fission cross-section |
| $\sigma_X$ | microscopic total absorption cross-section of Xe-135 |
| $\phi$ | total neutron flux in the fuel |
| $t$ | reactor time |



Analogue circuit for computing xenon concentration (Fig. 1)

Equations (1) may be simplified by writing them in terms of

$$X^* \equiv \frac{\sigma_X X}{(\gamma_I+\gamma_X)\Sigma_f} = \text{xenon concentration relative to the steady state concentration in an infinite flux}$$

$$I^* \equiv \frac{\sigma_X I}{(\gamma_I+\gamma_X)\Sigma_f} = \text{iodine concentration relative to the steady state xenon concentration in an infinite flux}$$

$$R^* \equiv \sigma_X \phi = \text{rate of neutron capture per Xe-135 nucleus}$$

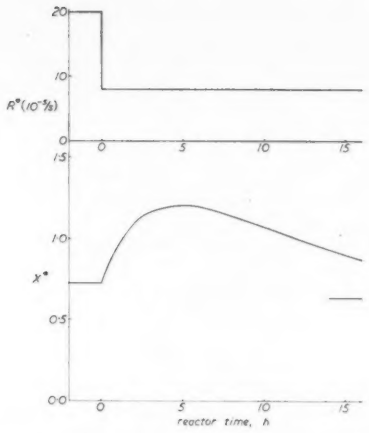
The new variables $I^*$ and $X^*$ are dimensionless numbers. As $\sigma_X \sim 3 \times 10^{-18}$ cm² and $\phi \sim 10^{13}$ n/cm² s in typical systems, $R^* = \sigma_X \phi$ is conveniently measured in units of $10^{-5}$/s. The numerical values are independent of the convention used for averaging the flux and cross-sections.

The resulting equations

$$\frac{dI^*}{dt} = \frac{\gamma_I}{\gamma_I+\gamma_X} R^* - \lambda_I I^*$$

$$\frac{dX^*}{dt} = \lambda_I I^* + \frac{\gamma_X}{\gamma_I+\gamma_X} R^* - \lambda_X X^* - X^* R^* \qquad (2)$$

are applicable to any reactor system, the only required data being the decay constants, the flux in units of $R^*$, and the proportion of Xe-135 produced direct from fission. Study of results for step changes and step cycles shows that this last parameter has little effect upon the results;



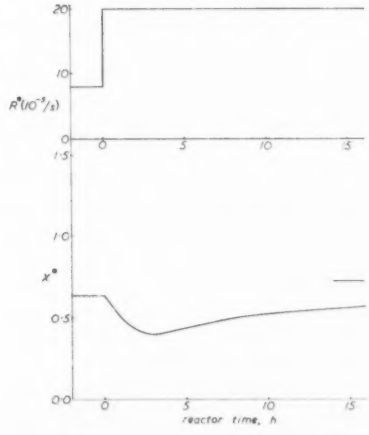

Xenon concentration after a step decrease in flux (Fig. 2)

values $\gamma_X/(\gamma_I+\gamma_X) = 1/13$ or 0 giving transient xenon concentrations which differed by less than 2% from those with the usually accepted value $\gamma_X/(\gamma_I+\gamma_X) = 1/26$, which was used in the majority of the present work.

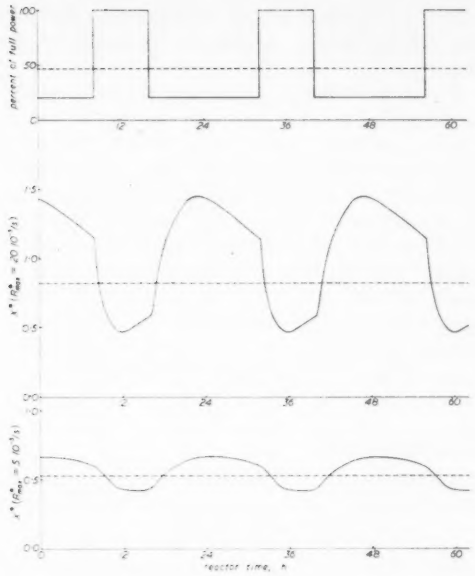
Equations (2) were solved by an electronic analogue computer, using basically the circuit shown in Fig. 1. The problem was scaled so that each minute on the machine represented a day on the reactor. In order to save machine time, two similar circuits with different scaling factors were used in parallel. The first circuit was scaled to maximum values $R^* = 20 \times 10^{-5}$/s, $I^* = 10$, $X^* = 2$, and the second to values $R^* = 5 \times 10^{-5}$/s, $I^* = 2{\cdot}5$, $X^* = 1$. The accuracy of the results is estimated as $\pm 0{\cdot}02$ on $X^*$ for the higher scale, and $\pm 0{\cdot}01$ for the lower fluxes, though some of the sharper transients were distorted by lags in the recorders which introduced an extra 1–2% error.

## Effects of step changes in flux

The changes in xenon concentration due to cyclic variations in flux can be understood by considering the effects of single step changes in flux. As the direct yield of xenon is small, a decrease in flux has little immediate effect upon the rate of production of xenon from iodine, but has a much more important effect upon the rate of destruction

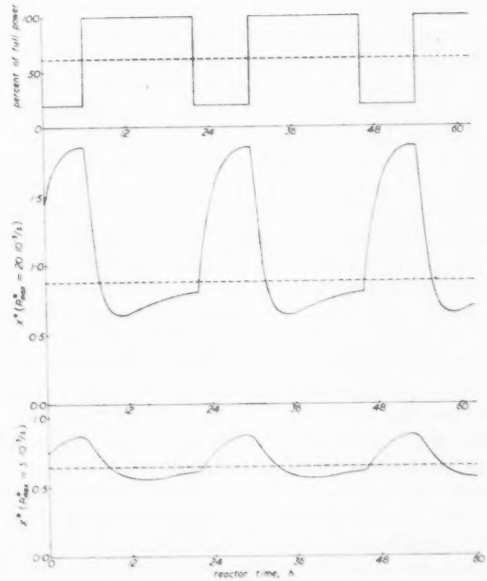



Xenon concentration after a step increase in flux (Fig. 3)




Xenon concentrations during step cycles, T = 16 h, dotted lines are the steady states with the same average power levels (Fig. 4)

of xenon. In typical gas cooled power reactors, $R^* \sim 3 \times 10^{-5}$/s, so that neutron capture is as important as radioactive decay, and a decrease in the flux leads to a large transient increase in the xenon population. Meanwhile the iodine population decays to the steady state corresponding to the new flux level, so the xenon population reaches a maximum value and then falls gradually to its new equilibrium level. This is illustrated in Fig. 2, which shows the effect of a step decrease from $R^* = 20 \times 10^{-5}$/s to $R^* =$



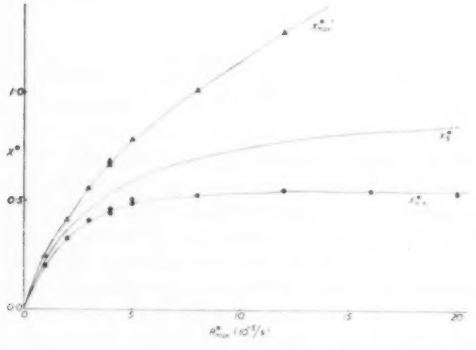

Xenon concentrations during step cycles, T = 16 h, dotted lines are the steady states with the same average power levels (Fig. 5)

$8 \times 10^{-5}$/s. The effect of the corresponding step increase in flux, shown in Fig. 3, may be explained by similar arguments.

In the cases considered, the peak xenon concentration was reached 3–7 hours after a step decrease in flux. For a constant initial flux, a decrease in the final flux increased the time taken to reach the peak value, and increased the amplitude of the transient. For example, the maximum xenon concentration after a reduction of from $R^* = 20 \times 10^{-5}$/s to $R^* = 5 \times 10^{-5}$/s was twice the initial concentration, and was reached after six hours. But when $R^*$ was only reduced to $16 \times 10^{-5}$/s, the maximum concentration was only a seventh larger than the initial value, and was reached in three hours. The xenon concentration took 2–5 times longer to decay past its initial value than it took to reach the peak concentration.

### Effects of step cycles

A comparison of results for step changes and ramp changes showed that the rate of change of flux had only

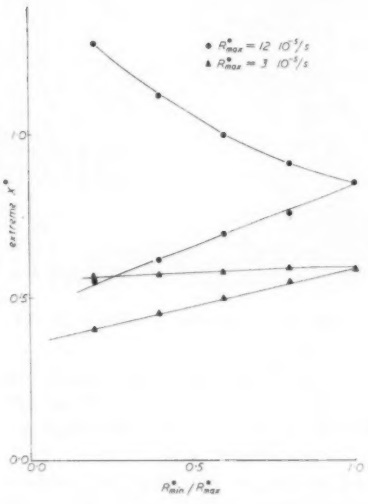


Xenon concentrations for step cycles between $R^*_{max}$ and $0{\cdot}2\ R^*_{max}$, T = 12 h (Fig. 6)

a small effect upon the magnitude of the xenon transient. It is therefore a convenient approximation to consider daily load cycles in which the analogue flux is $R^*_{max}$ for $T$ hours, and $R^*_{min}$ for the remaining $(24-T)$ hours. Results for ramp cycles are given in the next section.

Typical results for cycles in which the two flux levels differed by a factor of five, and $R^*_{max}$ was $20 \times 10^{-5}$/s or $5 \times 10^{-5}$/s, are shown in Figs. 4 and 5, for which $T$ is, respectively, 8 and 16 h. The dotted lines are the equilibrium concentrations at the steady flux level which produces the same total power per day. This shows the penalty which must be paid in order to generate power when required, instead of at a constant rate. This point is emphasized in Fig. 6, where $X^*_s$ is the equilibrium concentration at the steady state producing the same amount of power per day.

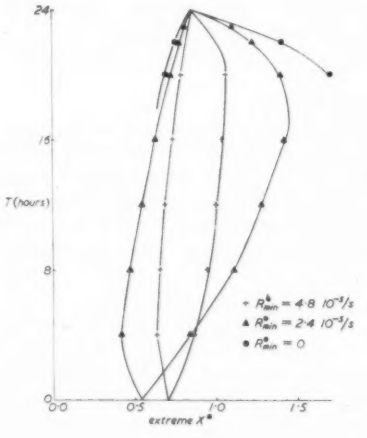
The effect of the ratio of the maximum and minimum fluxes during the cycle is shown in Fig. 7. For small changes, the amplitude of the variation of the xenon concentration during the cycle is proportional to $(R^*_{max} - R^*_{min})$. The other important variable is $T$, the effect of which is shown in Fig. 8. The maximum xenon concentration for cycles between two fixed levels occurs at $T$ = 16–20 h, but the maximum difference in levels occurs at $T$ = 14–16 h. These times are virtually independent of the peak flux level and the amplitude of the variation of the flux. The maximum xenon concentration determines the amount of reactivity which must be available in order to sustain any given cycle. The difference in levels largely



Extreme xenon concentration for cycles with T = 12 h (Fig. 7)

determines whether the cycle can be sustained without having to move the coarse control rods, or their equivalent.

Figures 6–8 present a sample of the results which were obtained for values of $T$ between 4 and 23 h, for $R^*_{max}$ between $1 \times 10^{-5}$ and $20 \times 10^{-5}$/s, and for $(R^*_{max} - R^*_{min})$ between $0{\cdot}6 \times 10^{-5}$ and $20 \times 10^{-5}$/s. The observed



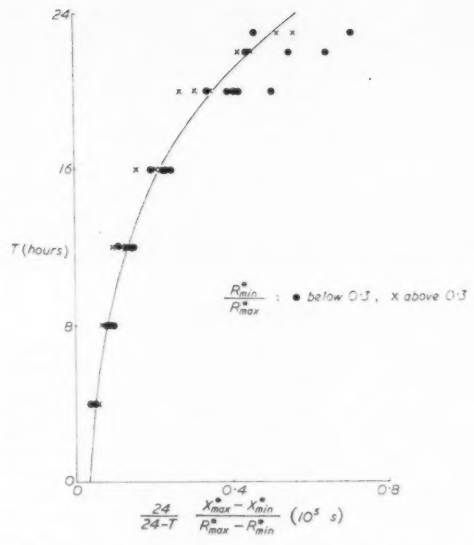
Extreme X*, the xenon concentration relative to the steady state concentration in an infinite flux, during cycles with $R^*_{max} = 12 \times 10^{-5}$/s (Fig. 8)

amplitudes $(X^*_{max} - X^*_{min})$ varied between 0·02 and 1·20. Figures 9 and 10 show that these results can be represented surprisingly well by the empirical relations

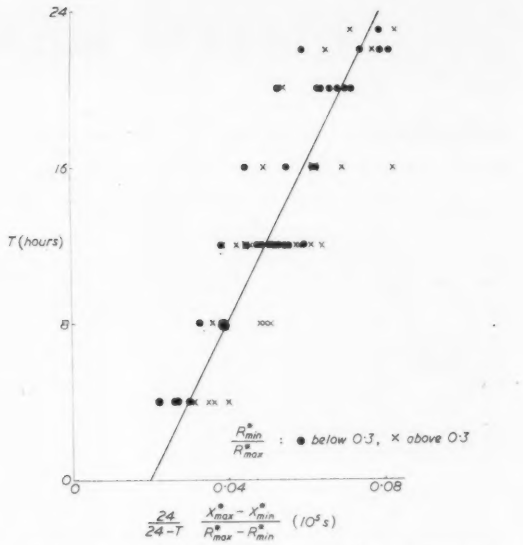
$$(X^*_{max} - X^*_{min}) = = 0{\cdot}032 \times 10^5\, e^{0{\cdot}12T}\, \frac{24-T}{24}\, (R^*_{max} - R^*_{min}) \quad (3)$$

and

$$(X^*_s - X^*_{min}) = = (0{\cdot}020 + 0{\cdot}0025T)10^5\, \frac{24-T}{24}\, (R^*_{max} - R^*_{min}) \quad (4)$$




This graph shows that the amplitude of xenon variations can be represented fairly accurately by the relation given in equation 3 (Fig. 9)




Tests of equation (4), which gives an empirical relation for xenon override (Fig. 10)

where $R^*$ is measured in $10^{-5}$/s. Equations (3) and (4) represent the results for a wide range of cycles and $T$ less than 20 h to better than $\pm 30\%$ and $\pm 40\%$ respectively. The scatter of the results is partly due to the inadequacy of the empirical formula, and partly due to the experimental errors, which were especially important for the small difference $(X^*_s - X^*_{min})$. It is surprising that the complicated exact analytic formulae for the differences $(X^*_{max} - X^*_{min})$ and $(X^*_s - X^*_{min})$ can be represented at all accurately by the simple empirical forms (3) and (4), especially in view of the non-linear nature of the equations. A better correlation would be obtained by using smaller ranges of the parameters.

Equations (3) and (4) are linear in $(R^*_{max} - R^*_{min})$. Hence the extreme xenon concentrations in a reactor can be calculated from the statistically averaged peak flux, if the flux distribution is assumed not to alter during the cycle. This greatly simplifies the practical problem of finding the reactivity which must be released to keep a reactor critical during xenon transients. Equations (3) and (4) are relatively inaccurate, but the resultant percentage error in xenon poisoning is much less than that in $(X^*_{max} - X^*_{min})$ or $(X^*_s - X^*_{min})$. For most purposes, and particularly for surveys, the approximation will be sufficiently accurate; more exact results can be obtained by making plots similar to Fig. 6 and using suitable averaging techniques.

## Other types of cycle

In the cycles so far considered, the flux changed instantaneously. Cycles in which the flux was altered at a finite rate were also studied. When the flux rose rapidly and fell slowly, both maximum and minimum levels were slightly lower than when it rose slowly and fell rapidly. If the flux was decreased over a period of 8 h, the override $(X^*_{max} - X^*_s)$ required in a typical case was 0·30, instead of the value 0·35 required for a step cycle producing the same power. The amplitude of the xenon variations was $(X^*_{max} - X^*_{min}) = 0{\cdot}76$ for the step cycle.

This agrees with results for single ramp changes, which showed that useful reductions in override could only be obtained if the reduction of power took several hours and if the power was decreased at least by a factor of two. The results for cycles in which reactor power was increased in two hours and decreased over four hours reactor time were practically the same as those for step cycles with the same extreme and average flux levels.

When studying the operation of reactors on a part load basis, it is necessary to consider the reduced demand at weekends. Results for step and ramp cycles show that reducing output by altering the maximum load or the portion of the day spent at full load did not increase the need for xenon override, which is principally determined by the peak flux level. The system takes 2–3 days of reactor time to reach effectively equilibrium conditions after a change of cycle. A return to mid-week conditions after a weekend causes a temporary decrease in the minimum xenon level, which might make it necessary to move the coarse control rods in order to maintain criticality.

## Conclusions

The concentration of Xe-135 at a point in a reactor can readily be calculated by an electronic analogue computer for any arbitrary variations in the flux level. If the equations are suitably transformed, the results are independent of nuclear data other than the half-lives of I-135 and Xe-135, and can readily be applied to any type of reactor.

The maximum and minimum xenon concentrations during step cycles in flux can be well represented by the two empirical equations (3) and (4). These are linear in the peak flux, so that the average xenon poisoning in a reactor can be readily calculated with reasonable accuracy from the average flux levels. Results for cycles involving ramp changes are very similar to those for the corresponding step cycles. This means that the xenon override does not depend upon the details of the load cycle.

**Acknowledgments**

The author would like to thank Messrs H. A. Darker and M. S. Fenton for their assistance in operating the computer, and to thank the English Electric Co. Ltd for permission to publish this paper.

# STUDENTS' NOTEBOOK

## GROUNDWORK—Information

*What guides are there to the literature on health physics and occupational safety?*

Guides to information in the rapidly growing field of nuclear energy and associated topics have already been discussed on this page. A field that has not been adequately covered, however, from an international angle (with the possible exception of 'Nuclear Science Abstracts') is that of health and safety, and it is one that concerns many of our research and training laboratories. It is a field, too, in which organizations all over the world are becoming very active, particularly on the aspect of legislation.

At the beginning of 1960 the International Labour Office, in collaboration with other organizations, through the International Occupational Safety and Health Information Centre, CIS, commenced an information service covering published literature, legislation and films on occupational safety and health.

National centres in London, Paris, Coblenz, Rome, Vienna, Brussels, Copenhagen, The Hague, Oslo, Stockholm and Lucerne regularly submit to CIS objective abstracts of every publication appearing in each of the countries represented, worthy of international recognition. Whilst the cooperation of agencies in other countries is being actively sought, CIS is itself analysing material from countries not yet covered in this way.

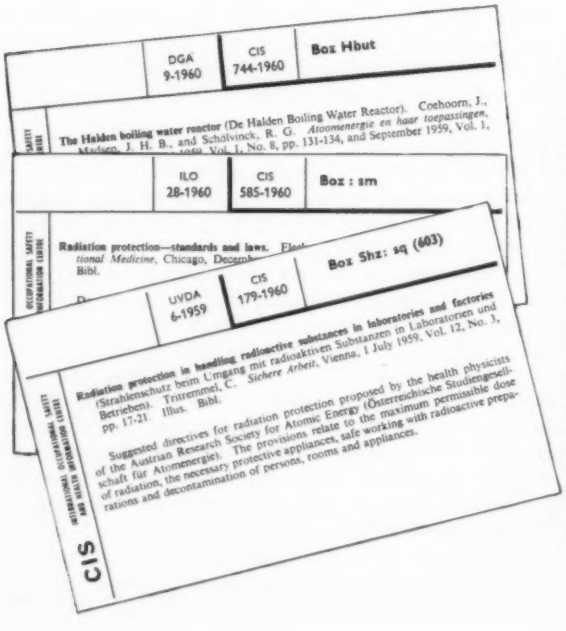
The scheme has a very wide subject coverage and includes every facet of health and safety, many of which may never be the concern of the subscriber to the service. In Britain some 150 organizations are participating.

Headings likely to directly interest our readers include: natural phenomena — covering ionizing radiations and ultrasonics; inorganic and organic chemicals —e.g. beryllium, graphite, fluorine, helium, molybdenum, sodium, uranium and zirconium; natural products and industrial substances—e.g. dust and gases; premises, equipment and operations — covering laboratories, nuclear and radiation equipment, pressure vessels and welding; methods of investigation—e.g. radiation monitoring, tracer techniques, radiographic and ultrasonic testing; safety and health engineering—including radiation protection, dust suppression and waste disposal.

The new information service is in the form of 5 x 3 in. cards divided into four classes, each of a distinctive colour. White cards are used for such publications as reports, books, periodical articles and the like; green for texts having the force of law—acts, decrees, orders and regulations; pink for publications not having the force of law but having the sanction of a recognised authority, e.g. standards, codes of practice, and ministerial circulars; yellow cards are used for films.

Only one card is published for each item of information but the necessary cross-references are compiled and despatched periodically to subscribers in the form of a cumulative alphabetical subject index, each new edition cancelling the preceding one. In this way, subscribers always have at their disposal a complete record of the subjects dealt with and of their different aspects.

In some ways it is unfortunate that only complete sets of cards can be purchased, the reason given is the interdependence of subjects and the cost of sorting to meet individual requirements. The annual subscription of £14 5*s* is made to the Industrial Safety Division of the Royal Society for the Prevention of Accidents who also undertake to provide (at cost) photocopies of the original papers abstracted, but not translations.


DGA 9-1960
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The Halden boiling water reactor (De Halden Boiling Water Reactor). Coehoorn, J., Madsen, J. H. B., and Schölvinck, R. G. Atoomenergie en haar toepassingen, Vol. 1, No. 8, pp. 131-134, and September 1959, Vol. 1,
ILO 28-1960
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Radiation protection—standards and laws. tional Medicine, Chicago, Decemb
Bibl.
UVDA 6-1959
CIS 179-1960
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Radiation protection in handling radioactive substances in laboratories and factories (Strahlenschutz beim Umgang mit radioaktiven Substanzen in Laboratorien und Betrieben). Trutzemmel, C. Sichere Arbeit, Vienna, 1 July 1959, Vol. 12, No. 3, pp. 17-21. Illus. Bibl.
Suggested directives for radiation protection proposed by the health physicists of the Austrian Research Society for Atomic Energy (Österreichische Studiengesellschaft für Atomenergie). The provisions relate to the maximum permissible dose of radiation, the necessary protective appliances, safe working with radioactive preparations and decontamination of persons, rooms and appliances.
CIS

The world's literature, laws, regulations, codes, standards and other texts of a legislative or instructive nature on all aspects of occupational safety and health are being given systematic coverage in this joint international abstract card service, operating through the International Occupational Safety and Health Information Centre (CIS) centred in Geneva. A special classification scheme has been devised that indicates at a glance the various facets of interest. On the top card, Boz = ionizing radiations; Shz = radiation protection; sq = drafts of laws; (603) = Austria

## NEWSBRIEFS

• Imperial College's new physics building, opened recently by Sir John Cockcroft, will provide for more than 300 undergraduates. It forms part of the comprehensive plan to double the size of the College by 1962. In his opening speech, Sir John made a plea for a British sponsored Atlantic Institute of Science and Technology, with powerful help from western Europe, as part of the country's university expansion programme.

• In a recent booklet 'Cooperation between Industry and Education' published by the Industrial Training Council, as an example of the cooperation already taking place, the UKAEA is mentioned. At one technical college in Scotland, 33 of a total staff of 36 are provided by the Authority.

• The University of Illinois has the first above-ground model of the Triga reactor. Apart from supported nuclear technology courses, it will produce isotopes for research work in other departments of the university.

• Women are to take engineering and science degree courses at the Rensselaer Polytechnic Institute in New York State.

• Griffin and George are producing a new series of teaching units for the demonstration of fundamental electrodynamical principles and the working principles of electromagnetic instruments.

• To commemorate its 25th anniversary, Ultra Electric held a special session of lectures on 'Electronics at work' at the Royal Festival Hall. Some 2000 boys and girls from London schools attended.

## UK COURSES

**Manchester College of Science and Technology.** Disposal of waste from the uses of radioisotopes—12 and 13 January, 1961. Fee £7.

## FILMS

• *Making electricity*. Part 1: principles and practice, 2 reels, 14 minutes. Part 2: sources and application of power, 1 reel, 11 minutes. *The national grid*, 2 reels, 18 minutes. All films are free for hire from the British Electrical Development Association.

• *Nucleonics in quality control*. 2 reels, 15 minutes. Free hire from E. K. Cole.

# Component fabrication for Hunterston

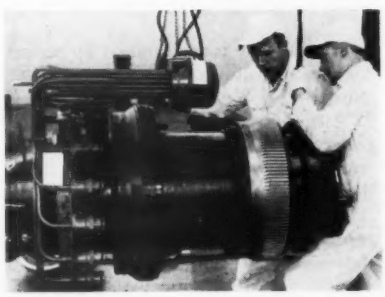
## clean conditions enforced

IN ALL STAGES of the manufacture of component parts for Hunterston, rigid clean conditions have to be observed to prevent the entry of those materials that are likely to affect criticality. It is particularly important that items close to the fuel elements, such as fixed channel tubes, stainless steel tubes in control-rod standpipes, channel cooling circuits, the charge machine, etc., are kept free of metallic dust at all stages of manufacture. Deposits of boron, cadmium and cobalt, and to a lesser extent, chromium, manganese, platinum, rhodium, tungsten and vanadium, are included in this prohibition.

These deposits and dust from aluminium, copper, molybdenum, nickel and selenium become highly radioactive and must therefore also be eliminated from such equipment as steam raising plants. They could cause false indications if allowed to settle near the burst cartridge detection equipment.

Both at GEC's Erith works, where the gas circuit plant is being made, and at the Glasgow works of Stewarts and Lloyds, where the 424 control rod standpipes are under construction, strict control of clean conditioning processes is enforced. Preliminary precautions taken in both factories were similar and consisted of sealing the floor with Sealocrite special sealer TP73C and, either painting the walls with a special gloss paint, or lining them and the ceiling with Laconite, a melamine surfaced hardboard. The clean areas are pressurized to prevent foreign matter from entering whenever a door opens.

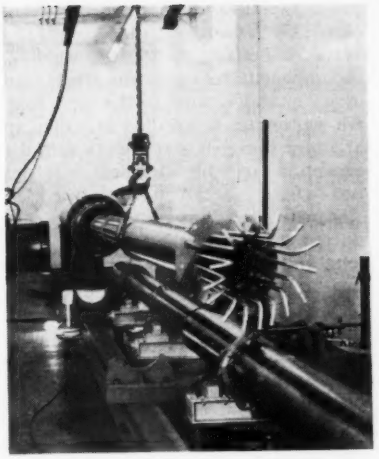
At Erith the ventilation and pressurizing plant consists of a 35,000 ft³/min air filter system and an air heater,



In addition to carrying the boron control rods, the standpipe contains the burst cartridge detection tubes. Here in Stewarts and Lloyds Glasgow works the loading rig is being fitted

fed by a 2·5 million Btu/h calorifier. A Sturtevant vacuum cleaning plant has been installed with the capacity

GEC's nuclear clean workshop, part of the existing process and preservation shop, consists of an assembly area and a reception bay which, with its sliding roof and 16 ft wide Potter Rax door, can be isolated for the final cleaning and inspection operations



Each of the 32 ft long standpipes consists of 63 tubes assembled to a very high degree of straightness, the various cavities being filled with concrete to act as biological shielding

for four operators working simultaneously at any of the seven points provided.

The cleaning and preserving processes consist of removing the scale, rust, dust and grease, coating components with a synthetic lacquer Trilac, or clean condition primers PA20 and PA21 produced by Federated Paints, followed by encasing in polythene containers. These contain a bagged dessicant of activated alumina pellets. Non-machined parts are shot blasted or pickled in an inhibited 10% solution of hydrochloric acid followed by immersion in phosphoric acid. Machined or bright components are immersed in a trichlorethylene vapour bath followed by a wash in a similar fluid and a 1–2 minute dip in phosphoric acid. When the plant is finally sealed in its bag, it is taken out of the building and stored under cover until needed on site. ★ 280

# Plutonium laboratory

## offers flexible facilities

The newest addition to the Battelle Nuclear Research Centre, which currently includes hot cells, a critical assembly laboratory and a 2 MW pool-type reactor, is a plutonium laboratory. Whilst the ANL plutonium fuel fabrication laboratory (*see October 1959, page 100*) is used exclusively for the fabrication of core loadings of fuel elements utilizing already developed fabrication procedures, the Battelle facility was designed as a very flexible research and development laboratory with only limited production capability.

All phases of plutonium work are integrated into one large room, each

phase having its own glove box complex. (*See November issue, page 112.*) When one phase, such as arc welding, is completed, the specimens are bagged in p.v.c. and carried to the next step. All plutonium is handled in either an argon or nitrogen atmosphere with the exception of the chemical analysis box where laboratory air is used.

Powder metallurgy studies are conducted in a stainless steel tank 16 ft long and 38 in. in diameter. This tank can be evacuated so that atmospheres may be changed simply by evacuating the tank and introducing the desired gas. Another stainless steel box is used for the dissolution and fuming of samples; all other boxes are made from mild steel and painted with acid-resistant paint. Wet chemical analyses are carried out in boxes with a controlled air velocity across the face openings.

A typical research study consists of two phases: alloy development and complete study of the alloy, and the use of this alloy to fabricate a prototype fuel element for use in irradiation studies. The first phase involves arc melting into either a button or finger bar, after which it is moved to a box containing a lathe where samples are cut and shaped for tensile testing, heat treatment, metallography, and fabrication. Chips are collected and moved to wet chemistry for analysis. The fabrication specimen is then assembled and welded in the welding chamber, moved to the fabrication box where it is evacuated and rolled on a 3 by 5 two-high mill. Specimens sent to metallography may have hardness tests or they may be polished and etched for study under a totally enclosed microscope where photomicrographs may be taken. ★ 281

# Bellows for nuclear power

## wide range of applications

For the production of a wide range of bellows joints, Munro and Miller are currently engaged in extensive research into processes and materials to suit many engineering applications. A programme of experimental and theoretical stressing has been carried out in conjunction with the Heriot-Watt College. These bellows are particularly useful for the large main ducts that take $CO_2$ to the steam raising units of nuclear power stations. They accommodate linear thermal expansion and contraction, absorb vibration, and allow greater movement than loops.

Each application influences considerably the bellows design. Whilst the more standard types are fabricated in various types of stainless steel and are welded to mild steel flanges, for corrosion use, fabrication may be in 'monel'. Bellows in this material range from 20 in. to 48 in. in diameter and accommodate 12 in. of movement with operating conditions in the range 40° to 170°F at 100 lb/in². In the chemical industry, 60 in. diameter monel bellows are used to carry steam containing salts in solution at pressures between 10 lb/in² and high vacuum. For higher temperatures and pressures, and where considerable movement has to be accommodated, equalizing rings are fitted to the bellows, these rings having the same contour as the convolutions when fully compressed. To reduce thinning effect to negligible proportions, convolutions are introduced hydraulically. Maximum ductility is maintained by means of heat treatment before and after forming.

Although automatic welding is used wherever possible in the joining of the convolutions and the flanges and other bellows components, much hand welding is nevertheless necessary, especially where the convolutions have been fabricated in stainless steel and the flanges are of mild steel. In such cases hand welding is carried out using Cooper & Turner Diadem Zircon HR2 electrodes. The chemical composition of these electrodes provides a barrier which overcomes the tendency towards the migration of carbon from one steel to another and its precipitation as a non-metallic boundary on the edge of the weld. This electrode is primarily designed for use with heat resisting steel such as 25% chrome 20% nickel containing molybdenum, the Diadem variant HR1 being employed for joining such steels as 23% chrome 11% nickel with tungsten to 18/8 type steel.

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Welding a bellows flange with a Diadem Zircon HR2 electrode, designed primarily for use with heat resistant steels

## Uranium recovery

### direct solvent extraction

Because phase disengagement is inhibited by the solids present it is not normally possible to use a solvent to extract a metal direct from an aqueous leached slurry. A rotary film contactor has now been designed, however, by the National Chemical Laboratory, for the UKAEA, that allows solvent extraction of metals direct from slurries. It does this by providing adequate interfacial area per unit volume for mass transfer without dispersing one phase in the other. As a result, the usual high cost of the liquid/solid separation phase is entirely eliminated.

The contactor consists of a number of disks on a common horizontal shaft; the rotation of the disks maintains solids in suspension in the pulp in the bottom half of the containing vessel. A film of pulp is carried over by the disks through the upper half of the contactor vessel containing the solvent. These contactors are being used for the continuous counter-current extraction of uranium from an approximate 50% solids ore pulp leached with sulphuric acid. The solvent is a solution of di-(2-ethylhexyl) hydrogen phosphate in kerosine modified by the addition of tributyl phosphate. ★ 283

## Measuring temperature

### radiation pyrometer

A radiation pyrometer and associated electrical circuits, capable of continuously measuring surface temperatures of metal bars in the range 650° to 750°C, travelling at rates up to 20 ft/min, has been developed by the UKAEA Development and Engineering Group.

Measurement is made in a $\frac{1}{4}$-in.–$\frac{3}{4}$ in. band between a heating zone and a quenching zone. A heat radiation transmission path is provided by a fused quartz rod, that has two breaks, the first for a rotary radiation chopper in the form of a slotted disk turning at a speed to give a chopping frequency of 1000 c/s, the second for a radiation chopper having alternate blades of Perspex and germanium and giving a 10 c/s frequency. A lead sulphide photocell at one end of the fused quartz rod receives alternate signals at 10 c/s on a 1000 c/s carrier signal.

The resulting signals from the cell, suitably amplified and rectified, are smoothed and transmitted to the slide wire and pointer of a potentiometer and presented to the ratio recorder of the pyrometer. The reading at the ratio recorder is a function only of the bar surface temperature.

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## Boiler water analysis

### continuous multipoint records

Cambridge Instruments have developed a multipoint boiler feed-water analyser for high pressure and high temperature boiler systems. The use of a highly flexible multipoint electronic recorder, special input circuits, and appropriate analyser units, enables the equipment to record several feedwater variables continuously and on the same chart.

Four separate variables can be recorded: dissolved oxygen and dissolved hydrogen content, conductivity and pH in any desired sequence, using a 6, 8 or 12-point electronic recorder. Other analyses, such as residual hydrazine, dissolved $CO_2$, etc, will be incorporated as development work proceeds.

The zero and sensitivity adjustments for each analyser can be made at the recorder, the lower part of which is fitted with a special pull-out tray that houses the necessary controls, although the analysers themselves may be located anywhere in the plant, thus simplifying maintenance and saving space.

The dissolved oxygen analyser works on the gas-transfer principle; oxygen is removed from the sample water by scrubbing with hydrogen, and its concentration is measured with an electrochemical cell. Accuracy is better than 0·0005 p.p.m. and interference from other substances in the water is eliminated. The dissolved hydrogen analyser uses the same principle. The conductivity of the sample is measured with a specially designed and highly sensitive circuit, and the readings are corrected for changes in the sample temperature. The pH meter uses a glass electrode, is temperature compensated, and the amplifier contains checking circuits for all components except the electrodes.

★ 285

## Neutron diffraction

### automatic spectrometer

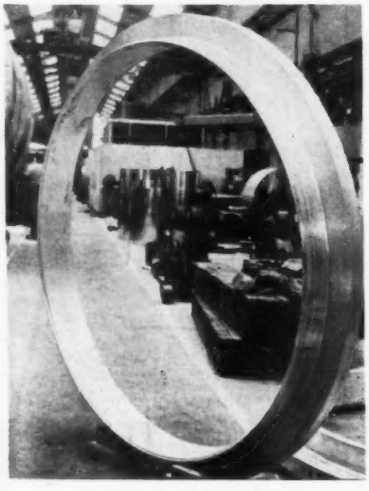
A neutron diffraction spectrometer that can be converted to automatic operation has been designed by M.A.N. of Augsberg for the Belgrade reactor at the Boris Kidrich Institute. Intended for the observation of dispersed neutron intensity, it consists of a counter, operated by a novel drive, that passes through a determined angle range at selected intervals. The neutrons dispersed on a specimen can be scanned at very small steps and recorded with electronic counters. The evaluation of these measurements provides information on the lattice structure of solid materials.

A similar instrument has already been supplied for the Garching reactor. Another has been ordered for the Dido reactor at Julich equipped with automatic position indication suitable for programming. The latest development, however, is the Karlsruhe design that is to be programmed and controlled by teleprinter from the Stuttgart Institute of Technology.

★ 286

## IN BRIEF

**ALUMINIUM CORE SHELLS** Work has recently been completed on the forging of four aluminium alloy rings, part of the core shells for the Swedish 30 MW MTR reactor at Studsvick and the 20 MW reactor at Petten in the Netherlands, both of Allis Chalmers design. Believed to be the largest forged aluminium rings ever produced in this country, each unmachined ring weighs some 1300 lb, with an outside diameter of 76 in., an inside diameter of 61¾ in., and a thickness of 8¼ in. The rings were forged by Alcan; the ringing operations being performed on a 1200 ton hydraulic press and the flattening operations on a 4000 ton press. APV, who are making the core shells, are responsible for the machining operations ★ 287



**NUCLEAR PROPULSION** To drive the 25 kt US aircraft carrier 'Enterprise' are 8 PWR Westinghouse reactors. The land prototype at Idaho, consisting of two reactors and the machinery for one of the carrier's four shafts, has been operating in tandem since September 1959. ★ 288

**MICROWAVE MEASUREMENT** An adjustable sliding waveguide termination, that reduces reflections to a minimum in microwave measurements, has been developed by the US National Bureau of Standards. The instrument has a minimum voltage standing wave ratio of less than 1·0002, or a return loss greater than 80 db. ★ 289

**VIEWING NUCLEAR PARTICLES** Although originally designed for applications in astronomy, the Westinghouse Astracon tube, a powerful image amplifier, will make it possible to see the light-trails of high-energy nuclear particles in luminescent crystals. ★ 290

**WELDING IN USSR** Two new promising processes under development in Russia are Friction welding that uses no external heat and is limited to components of cylindrical or disk-shaped sections, and Diffusion welding for joining dissimilar materials. ★ 291

**ISOTOPE SEPARATION** Gram quantities of osmium isotopes have been separated at Oak Ridge, using an electromagnetic process. A volatile form of osmium oxide was used as the feed material. ★ 292

**MEGAROENTGEN DOSIMETRY** X- and gamma-ray exposure doses in the megaroentgen range can now be measured by means of a simple film method developed by the National Bureau of Standards. Using commercially available film, photographic processing is not required, the darkening of the film is read directly with a conventional photoelectric densitometer. ★ 293

**IRON CORROSION** Towards a basic understanding of the process involved in iron corrosion, Westinghouse have been conducting experiments that eliminate the conditions required for electrochemical reactions, originally considered to be the cause of corrosion. The new theory developed suggests that hydrogen ions that come from water vapour penetrate the iron and enlarge the sites at which oxygen normally combines with the metal, thus spreading the reaction throughout the surface of the iron. ★ 294

**PLUTONIUM MILLING** To facilitate remote control, the new Loma rolling mill at Argonne is equipped with a mechanized roll changing device comprising a roll storage car, three slideways to carry three roll assemblies, quick-disconnect screwdowns and universal spindle supports. Complete roll changes can be performed in a few minutes. Special cartridge heating elements are mounted in the rolls to prevent undue chilling of the materials being hot worked. ★ 295

**ROTATING REACTOR CORE** US Patent 2,940,915 relates to a high temperature reactor comprising a stationary housing and a rotatable annular core. Disposal of spent fuel elements is possible by way of the cylindrical space along the core's axis, fresh elements, inserted under pressure, is by way of the core's cross section outer periphery. ★ 296

★ *For further information on any item circle the appropriate number on the reply card facing page 150.*

# New Product Survey

EQUIPMENT · INSTRUMENTS · MATERIALS

## DIGITAL CONTROLLER

### small scale computer

A small scale single purpose digital computer, Optimat, has been designed specifically by Panellit for industrial process control applications. The machine accepts input signals (quality, flow, temperature, etc.) from the process and, in turn, operates on the set points of up to three conventional three-term controllers. The set points are adjusted in such a way that optimum performance of the plant is obtained, whilst the process is retained within specification limits.

Optimat operates by making a small change to the set point of one of the variables and observing the effect of this change on both the specification and the criterion to be optimized. As the optimum operating point changes due to the presence of uncontrolled variables, the process is continuously adjusted to the new optimum operating point.

The computer may be connected directly to existing controllers, whether they be electrical, pneumatic or any other form.

Optimat is completely solid state, requires no programming nor knowledge of the process transfer function.

★ 208

## FILM BADGE EXPOSURES

### rapid evaluation

For the purpose of film badge measurement, radiation dosage is a function of density appearing on the film. This density may be defined as the logarithm of the ratio between the light entering the film and the light leaving it.

The Eberline FD-11 film densitometer, which uses this principle, is basically a null-balance, closed-loop system of density measurement. A light source and a light chopper provide two equal beams of alternating light. One light beam passes through light-absorbing wedges, the unknown film, and into a light-integrating sphere. The wedges are a pair of counter-rotation glass density disks, whose combined density varies linearly around the circumference of the disks. The other light beam passes through a fixed density and a zero adjustment wedge into the light integrating sphere.

The Eberline FD-11 densitometer is designed to provide rapid evaluation of film used to determine radiation dosage

In case of a density unbalance in the system, a 60-cycle variation in the light flux entering the photomultiplier occurs. Difference in the total densities introduced into the beams is translated into a peak photomultiplier output voltage signal proportional to the light difference between the two entering beams. This difference, when amplified, operates the servomotor and drives the balancing wedges in the direction that will decrease the difference. As the instrument approaches balance, the difference becomes continually smaller until it reaches zero or becomes too small to operate the servomotor. The system is now in balance and the position of the balancing wedges is a function of the density of the unknown film.

Density is read directly from the counter by setting an initial balance point with the zeroing wedge and reading the difference from a new balance point when an unknown film is introduced.

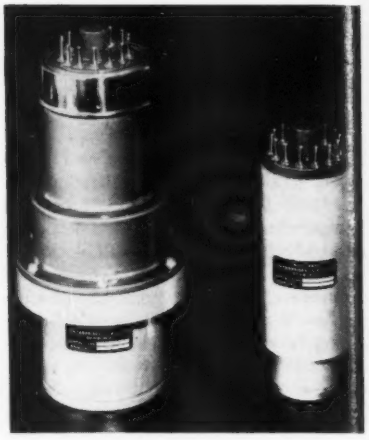
★ 209

## RADIATION DETECTION

### crystal-photomultipliers

Nuclear Enterprises now have available a completely new range of scintillation crystal head units using NaI(Tl) crystals ranging from 0·015 in. up to 9 in. dia. Other crystals are available for alpha, beta and proton detection. Advantages claimed are improved gamma resolutions, the elimination of optical and light-tight problems and the provision of special low background assemblies and pre-amplifier-dynode chain units.

The assemblies fall into two main classes. In the integral assembly, used for all crystals up to and including 2 in. dia. the crystal is mounted directly on to the photomultiplier face. In the IA-HG thin crystal assembly, the crystal, of course, is mounted independently. In the demountable assemblies, used for crystals with diameters in the range 2–5 in., crystals are independently mounted and viewed through an optical window. This facilitates ready replacement of the photomultiplier and precludes the need to return the assembly for replacement.



The new range of scintillation crystal head units from Nuclear Enterprises fall into two classes; the demountable assembly (left) for crystals 2–5 in. and the integral assembly for thinner crystals

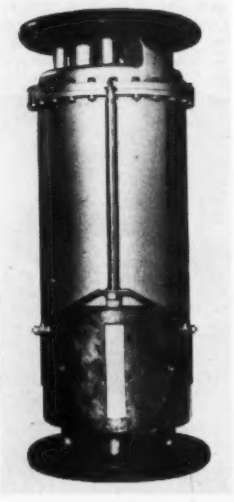
For applications where very low level activities are to be measured, special low background assemblies, type DM-LB, are available that employ quartz windows, stainless steel canisters and de-based photomultipliers.

★ 210

## INDUSTRIAL RADIOGRAPHY

### portable X-ray unit

To meet the demand for a portable unit for weld examination, with a particular application for circumferential inspection of small diameter pipes, Pantak have introduced the Baltospot G150, a new 150 kV X-ray unit.



The Baltospot G150 X-ray unit from Pantak is 1 ft 9 in. long and 8½ in. dia. and weighs 46 lb

The instrument is available in two models, the type D head having a 60° field and the type P with a 360° field. The focal spot size of the tungsten target is 1·5 mm × 1·5 mm in the E150D whilst that for the G150P is 0·8 mm × 2·1 mm. A particular feature of the head, which is offset, is its use in the examination of closed vessels of small diameters, a 3 ft dia. tubular vessel with a welded dished end being well within the capacity of the unit.

Sulphur hexafluoride is used for both insulation and cooling of the X-ray tube, forced circulation cooling of the anode being effected by means of an internal blower. Stepless type kV and tube current controls are incorporated in the control unit to give continuously variable control.

★ 211

## FLOWMETER CALIBRATION

### self-contained unit

Fischer and Porter Ltd. have introduced a complete calibration unit which may be used for flowmeter calibrations up to a maximum flow rate of 60 gal/min (water). Standing 9 ft high, on an area of 8 × 4 ft, it is a completely self-contained unit.

Water is passed through the instrument being calibrated at a manually controlled constant rate, after which it is then collected in one of the calibrated measuring vessels. The whole operation is timed and the reading of the measuring vessel is taken from the appropriate calibrated sight glass.

The unit incorporates three measuring vessels; the low one has a capacity of 1 gal and is calibrated in 1/10 gal intervals; the medium has an 8 gal capacity and is calibrated in 1 gal intervals, and the high has a capacity of 60 gal and is calibrated in 4 gal intervals.

★ 212

## PACKAGED AMPLIFIER

### three units combined

Cubic Corporation's Model 1100 amplifier, combines the features of three individual units in one package: a differential-input wideband d.c. amplifier, a bridge balance circuit, and a well regulated strain-gauge power supply.

In instrumentation applications where a self-contained power supply is not essential, two d.c. amplifiers can be combined in a single unit, increasing from 8 to 16 the number of amplifiers that can be mounted abreast in a standard 19 in. rack. Cubic's Model 1000 chassis can be used with this new amplifier to provide any required gain, fixed or variable, and single-ended or differential input.

★ 213

The new Cubic d.c. amplifier requires no separate power supply or bridge balance circuits

## LEVEL RECORDER

### continuous measurement

A continuous level indicator, offering stability and freedom from drift, has been produced by Electronic Machine. The 'Contimitor' employs a crystal oscillator with full temperature and mains compensation and a matched transmission line connects the instrument to its probe or transducer; cable lengths of up to one hundred yards can be used without loss of stability.

A capacity change of 10 pica farads will give a reading over a range of nil to full scale on a 1 milliamp meter. In cases where extreme sensitivity is required, provision can be made to give 0·03 pica farads for 1 milliamp change in output.

If it is used in applications such as continuous level monitoring in tanks, where high minimum values of capacity are encountered, with relatively large changes in capacity as the level rises, provision is made for tapping down the coil at the probe end, thus accommodating a wide range of probes or transducer conditions.

★ 214

## X-RAY DIFFRACTION COUNTER

### automatic operation

Hamner's new N-276 scaler is designed for use in systems where high speed and/or automatic operation is indicated. It can be combined with N-803 printing timer to form a scaler-timer system.

The unit features fifteen preset counts from 10 to 500,000 counts and is also operable in preset time and manual modes. It is also possible to preset both counts and time in any combination, with the occurrence of the first preset event stopping the counting system.

The Hamner scaler has a pulse pair resolution of better than 1 microsecond, a repetition rate of 1 megacycle, and a display of 6 electronic decades. ★ 215

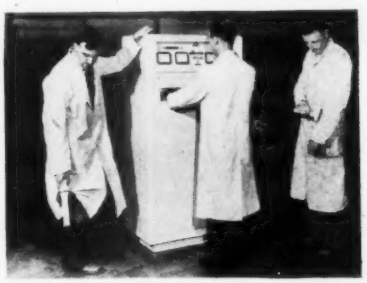
The Hamner N-276 high speed printing scaler has a sensitivity of ± 4 volts peak minimum

## RADIATION MONITOR

### hands and clothing

The hand and clothing monitor Type 1, developed by EMI Electronics, can check a person's hands simultaneously for alpha and beta contamination, and at the same time monitor the clothing of two other people.

The use of a dual phosphor-ZnS(Ag) and plastic phosphor, with an area of 8 in. × 5 in., in the hand counters halves the counting time and gives five seconds at the normal permissible level. The integrated counts are displayed on four meters, and audible and visible warnings are given as soon as the n.p.l. is exceeded.



EMI's contamination monitor is useful when large numbers of people need checking in a short time

Two other independent probes are used for monitoring clothing; a ZnS(Ag) on perspex scintillation counter for alpha contamination, and a geiger-müller counter type B12H, with cathode follower, for beta-gamma contamination. Background radiation, which is continuously monitored by a plastic phosphor counter, is subtracted from the total measured count. ★ 216

## PLATING THICKNESS METER

### coulometric principle used

A plating meter for measuring the thickness of most industrial platings is being manufactured by Nash and Thompson. Using the coulometric principle, it strips the plating from a standard area and measures the integration of time and current density, an operation that normally takes a few minutes. The thickness of the plating is determined from a dial

reading and a multiplying factor.

The meter will measure thicknesses in the range 0·000004 in. to 0·0015 in. in the following combinations: chromium on nickel; nickel on aluminium, steel, brass or copper; copper on steel or zinc; cadmium on steel; and zinc on steel.

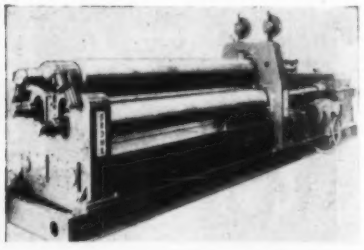
★ 217

## PLATE BENDING

### 3-roll pyramid machine

Bronx Engineering has recently introduced a new range of bending rolls of the pinch/pyramid type. Consisting of three rolls, vertical adjustment, either independent or simultaneous, is made with the two bottom driven rolls.

With a capacity for pre-bending and rolling mild steel plate 10 ft in width and ¾ in. thick, both long edges of the plate can be performed prior to rolling without taking the plate out of the machine. For the removal of completed cylinders, the top roll is balanced from the drive end,



In the Bronx PPP410 pinch/pyramid rolls, the roll necks extend outside the housings on the swing down end and allow various types of roll to be fitted that can be used for the bending of angles and other sections

and at the non-drive end the bearing housing swings down. Both operations are controlled pneumatically by one control movement.

Large indicator dials are fitted at the drive end to register the movement of the bottom rolls.

★ 218

## RADIATION DETECTION

### personal monitor

A miniature radiation detector with built-in speaker and flashing neon lamp, the Wallac type RDM, is available from Griffin & George. Designed in Finland for gamma and X-radiation indication, the instrument is powered with two standard 1·5 V batteries, weighs 5 oz and fits into the pocket.

It comprises an oscillating transistor, transformer, rectifier, filter, ionization tube and crystal speaker. Background radiation is indicated by a 20 pulse/s signal whilst intensities of from 2 mr/h to 2 r/h give rise to a loud crackling sound varying according to radiation strength.

★ 219

# IN BRIEF

• **Potentiometric recorder** Aveley's new 10-speed d.c. chart recorder incorporates very high input impedance of up to $10^{11}$ ohms, a fully floating input and ten different chart speeds, selected by push-button control. Direct connexion is permitted of circuits such as diode rectifiers, discriminators, photo-electric multipliers, etc.

★ 220

• **Laminated aluminium.** Bakelite's Warerite aluminium, which has been supplied for the 'Dreadnought', consists of decorative laminated plastics bonded to an aluminium core—6, 8 and 10 gauge. It is very clean, impermeable, splinter proof and of great strength.

★ 221

• **Rust prevention.** Galvalloy, a compound of anodic metal particles suspended in a plastic anti-corrosion medium, has been developed by Stewart Wales Somerville for ferrous metal protection.

★ 222

• **Time indicator.** The Selachron series of compact, electro-chemical, elapsed time indicators introduced by Industrial Instruments record the total operation time of electrical equipment. Each indicator weighs under 2 oz. and is 2¾ in. long with a diameter of 1 in.

★ 223

• **Radioactive decontamination.** SDG3 powder from the Standard Chemical Co. is suitable for removing radioactive metal contamination from metallic and other hard surfaces and from textile materials. It takes the form of a white granular free-flowing powder and is diluted with water for application.

★ 224

• **Air breathing apparatus.** Siebe Gorman's Mark IV self-contained compressed air equipment consists of a cylinder containing some 1200 litres charged to 132 atmospheres and a mask with a valve that opens on inhalation and closes on exhalation. A second mask can be connected that enables two persons to breath air from the one cylinder.

★ 225

• **Oscilloscope camera.** Thompson's new oscilloscope recording camera, Series 410, supersedes the 400 and is now fitted with an iris diaphragm stopping down to f/32 and a between lens compur shutter, with speeds ranging from 1 to 1/125th second.

★ 226

• **High vacuum valves.** For the automatic control of vacuum apparatus, an improved range of magnetic valves is available from NGN Electrical in standard sizes of ½ in. and 1 in. Larger types may be supplied.

★ 227

• **Semiconductor devices.** Texas Instruments have introduced a new series of semiconductor devices which include the first commercially available gallium arsenide tunnel diode; high-speed switcher transistors, both germanium and silicon; high voltage rectifiers; and a completely new range of zener voltage reference diodes.

★ 228

• **Voltage measurement.** Using a new low impedance adaptor, Wayne Kerr's B601 r.f. bridge will now give an overall measurement down to 1 milliohm, 1 milli-microhenry and up to 5000 microfarads.

★ 229

• **Inductance measurement.** Designed for operation over a frequency range from 25 to 3000 c/s, Furzehill's B810A incremental inductance bridge and associated units give direct reading of inductance and Q with or without d.c. flowing.

★ 230

• **Arc welding electrodes.** Lincoln have added to their range of electrodes the 'NuFive', a cellulose type for welding mild steel, and the 'NuSeven', an iron powder-rutile type for general mild steel application.

★ 231

• **Vacuum gauges.** Edwards' latest 'Speedivac' Penning type gauges cover the range 10 torr to $10^{-11}$ torr. Suitable for industrial use, they are robust and employ simple circuitry.

★ 232

• **Valve testers.** Taylor's have released a new valve tester, type 45C, capable of testing over 5000 different types of valves. It has 2 ranges of mutual conductance, 0–3 mA/V and 0–5 mA/V.

★ 233

• **Precision potentiometer.** General Controls are producing a size 05 servo or bush mounted precision potentiometer, that has a maximum value of 20,000 Ω, with tappings in 3 positions to order. The best practical linearities are 100 Ω to 10,000 Ω ± 0·5%, 1000 Ω to 10,000 Ω ±4 %, 10,000 Ω to 20,000 Ω ± 0·3%.

★ 234

• **Level indicator.** Rank Precision's electronic level indicator, 'Talyvel', checks levels horizontally or vertically and uses a pendulum in conjunction with transducers that provide an electrical displacement signal.

★ 235

• **Wide-band amplifier.** For use as a laboratory instrument, 1–155 amplifier of Consolidated Electrodynamics is designed to amplify low-level transducer signals over the d.c. to 10 kc range. It attains a common mode rejection of 120 db from d.c. to 1·5 kc and 140 db at 60 cps and has a peak to peak output of 200 mA, 20 V.

★ 236

• **Circuit breaker.** A new 132 kV oil circuit-breaker, type LG6C, produced by AEI, is of three-tank monobloc design and has 60% less oil content than earlier designs.

★ 237

• **Refractory materials.** Suitable for uses around 1700°C, Spicer's Zirconite, comprising high-purity zircon, and available in handy stock billets, can be sawn, drilled, filed, turned and shaped.

★ 238

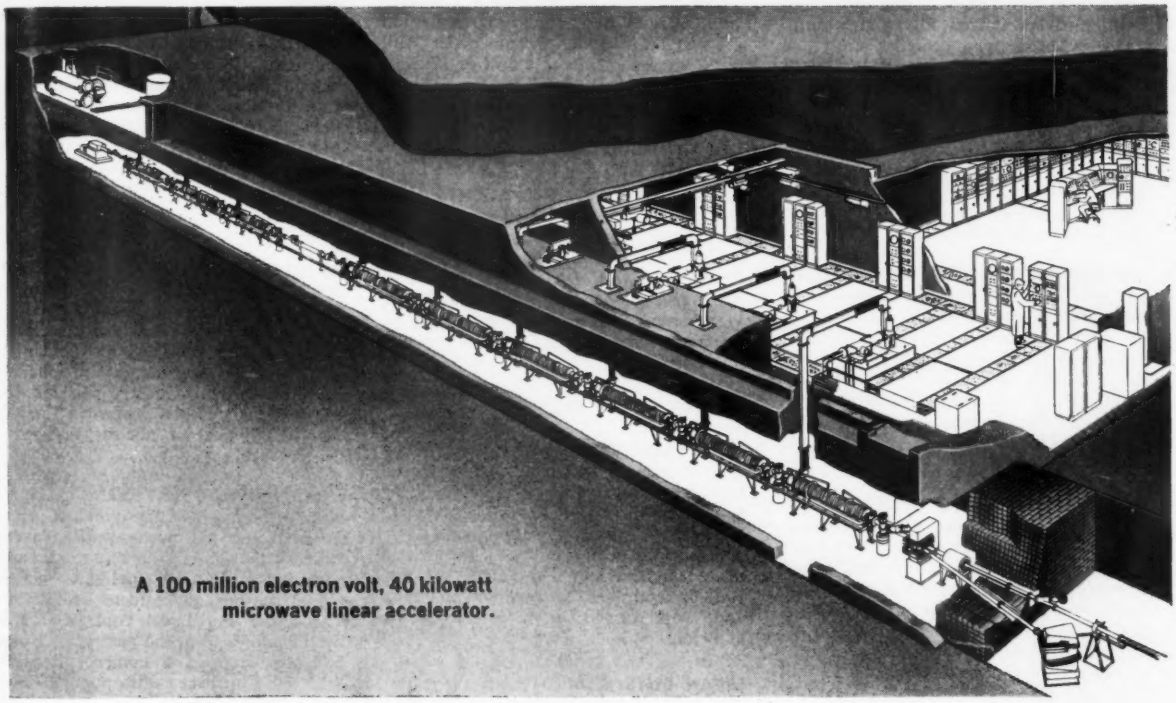
• **Thickness gauge.** Steel of up to 8 mm thick can be tested by the Solus-Schall type 2211 magnetic thickness gauge. Consisting of a control unit and a magnetizing probe, the 30 lb equipment is transportable.

★ 239

★ *For further information on any item, circle the appropriate number on the reply card facing page 150.*

# SETTING NEW STANDARDS

## at 99.98% of the speed of light



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... to meet the need for new data in the growing field of applied radiation.

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60 Carpenters Wood Dr.
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Telephone: Field End 7431



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# BUSINESS NEWS

**NEW HAWKER SIDDELEY AGREEMENT** *Spembly Ltd and Hawker Siddeley Nuclear Power Company Ltd* are to co-operate in the design, manufacture and selling of specialized high temperature furnaces of a type designed and now being commissioned by Spembly at Hawker Siddeley's Langley works. Some details of Spembly's work in this field were reported in *Nuclear Power*, February 1959, p 92. The current furnace is said to be four times larger than anything of its type and is expected to play an important part in research in the nuclear and high temperature field.

**DATA PROCESSING SERVICE** An organization which can perform data processing on a commercial basis has been set up by *de Havilland Propellers Ltd* at their factory at Stevenage. It is believed to be the first such service generally available to industry in the south of England and work has already been undertaken for the *Central Electricity Generating Board*, and the *UKAEA*.

**MORE TRAWSFYNYDD ORDERS** Temperature data handling equipment, designed and manufactured by *Blackburn Electronics Ltd*, is to be installed in the Trawsfynydd nuclear power station being built by *Atomic Power Constructions Ltd*. This will be the first installation of the Yorkshire company's equipment in a power station to be connected up to the national grid.

**PLESSEY EQUIPMENT FOR THE US** Burst slug detection equipment for the Westinghouse Test Reactor at Waltz Mill, Pennsylvania, was delivered recently by *Plessey Nucleonics Ltd* to the *Canadian Westinghouse Company*. It is to be incorporated in an experimental, high pressure gas loop.

• An *IBM* 7090 data processing system has replaced the IBM 709 which has been in operation at the *United Kingdom Atomic Energy Authority* since July 1959.

• An *AEA*-owned *Mullard* mobile linear accelerator is to be used at Trawsfynydd for checking pressure vessel welds. It is expected on site shortly.

## OVERSEAS

**AEC ENGINEERING MATERIALS** The *USAEC* has arranged to make available at greatly reduced costs, copies of engineering materials covering almost every aspect of the nation's nuclear energy programme. The materials include drawings, photographs, sketches, design criteria, specifications and parts' lists which have been prepared as part of various engineering and construction programmes carried out by the AEC and its contractors. Contractual arrangements have been completed with *Cooper-Trent Blueprint & Microfilm Corporation*, 2701 Wilson Boulevard, Arlington 1, Virginia, to supply on order, full sized blueline prints at a cost of 17 cents per square foot, FOB contractor's plant, with substantial discounts allowed on larger orders. Requests for prints should be addressed to Cooper-Trent.

**CANADIAN COBALT-60 AGENTS** High specific activity Cobalt-60 sources for radiography are now being distributed in the UK for *Atomic Energy of Canada* by the *Industrial Division* of *Watson & Sons (Electro-Medical) Ltd*, of North Wembley, Middlesex. A wide variety of standard sources made up from this high specific activity (100 curies/g) is now available and can be fitted into the various containers in use today.

**SENN VALVE CONTRACT** All the valves for the Senn nuclear power station being built near Naples are to be supplied by the Dutch firm, *G. Dikkers & Co* of Hengelo. The order was obtained in open competition with US and European firms. Dikkers supplied valves for the Halden reactor in Norway and has also done work for the Dutch research centre at Petten.

**JAPAN BUYS GRAPHITE KNOW-HOW** The *GEC* has concluded a long term agreement with *Nippon Denkyoku Kabushiki* (Nippon Electrode Co. Ltd) covering the manufacture in Japan of a special type of graphite developed by GEC laboratories for use in nuclear plant. The agreement is initially for ten years and is subject to approval by the UK and Japanese governments. Nippon Denkyoku will be able to sell the two types of graphite involved—low permeability and substantially impermeable—anywhere in the world, with the exception of the UK. A new plant for manufacturing this graphite is to be built in Japan.

**DEGUSSA INTERESTS TRANSFERRED** *Degussa* (Deutsche Gold-und Silber-Scheideanstalt Vormals Roessler) has transferred its interests in the nuclear field to *Nukem* (Nuclear-Chemie und Metallurgie GmbH). Degussa personnel undertaking research will move over to Nukem and the firm's installations in Wolfgang, near Hanau, will go to Nukem.

**ACCELERATOR FOR SA UNIVERSITY** An offer of £100,000 has been made by the South African mining industry towards the cost of a nuclear accelerator and ancillary buildings for the University of the Witwatersrand in Johannesburg. The mining industry also contributed £800,000 recently toward a fund for the development of nuclear research in the Union.

**URANIUM RECOVERY CONTRACT** *Nuclear Materials and Equipment Corp.* of Pennsylvania has been awarded a contract by the USAEC to recover uranium content from nuclear fuel scrap generated at various government installations. This is the fourth such contract received by the company in the past year. Numec has also received a contract from the AEC to produce ultra-pure hafnium metal. This will be used as a control material in connexion with the AEC's naval reactors programme.

**SWEDISH COMPUTER CENTRE** Part of the Swedish Aircraft Company's (SAAB) Jonkoping analogue computer centre which started operations earlier this year. SAAB only recently released details of the centre which is equipped with a PACE 231 R computer system

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# NASHTON

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# Diary

24 NOVEMBER
*Atomic reactions studied by spectroscopy*, Hull University. Details, Chemical Society, Burlington House, Piccadilly, London, W1

25 NOVEMBER
Symposium, *New materials of interest to the Physicist*, London. Details, the Secretary, The Institute of Physics and The Physical Society, 47 Belgrave Square, SW1

28 NOVEMBER—9 DECEMBER
IAEA Regional library workshop on *literature in the field of nuclear energy*, Manila

29 NOVEMBER
*Nuclear Temperature Scanning* Symposium, The Society of Instrument Technology, London. Details, 20 Queen Anne Street, London, W1

29 NOVEMBER—2 DECEMBER
*Corrosion and Metal Finishing Exhibition*, Empire Hall, Olympia, London. Details, 9 Eden Street, London, NW1

30 NOVEMBER—2 DECEMBER
*Steels for Nuclear Reactor Pressure Circuits* Iron and Steel Institute at Hoare Memorial Hall, Church House, Great Smith Street, London, SW1

2 DECEMBER
Films, *Dounreay Fast Reactor, Isotopes in Industry*, at Junior Institution of Engineers, Pepys House, 14 Rochester Row, Westminster, SW1

4–7 DECEMBER
Annual meeting, American Institute of Chemical Engineers, including sections on *nuclear reactor operations*, Washington

4–9 DECEMBER
Annual meeting, Radiological Society of North America, Cincinnati

5–8 DECEMBER
Fifteenth Annual Meeting and Astronautical Exposition, Washington. Details, Roderick L. Hohl, American Rocket Society, 500 Fifth Avenue, New York, 36

5–9 DECEMBER
IAEA Symposium on *Pest Control by Radiation*, India

6 DECEMBER
*Welding processes, design of pressure vessels*, etc, Birmingham meeting organized by the British Welding Research Association

7 DECEMBER
*Recent developments in the welding of pressure vessels*, Dr H. Harris, Glasgow. Details, The Institute of Marine Engineers, 76 Mark Lane, London, EC3

*Dounreay Fast Reactor* Symposium (arranged under aegis of British Nuclear Energy Conference), Institution of Mechanical Engineers, London, SW1

*Radioactivity in relation to water supplies*, Newport Meeting, Society for Analytical Chemistry and Cardiff and District Section, Royal Institute of Chemistry

7–11 DECEMBER
IAEA regional symposium on *education and nuclear energy*, San Carlos de Bariloche, Argentina

8 DECEMBER
*Dragon project*, Dr L. R. Shepherd, at Liverpool University, Liverpool and North Wales branch meeting, The Institute of Physics and The Physical Society

*Some designs aspects of gas-cooled nuclear power stations*, Bristol University. Arranged by the Chemical Society, Royal Institute of Chemistry, Chemical Engineering Group and Institute of Metals

11–14 DECEMBER
*Eighth Hot Laboratory and Equipment Conference*, San Francisco. Details, James R. Lilienthal, Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, New Mexico

12–14 DECEMBER
Winter Meeting of the American Nuclear Society, San Francisco, California

12–15 DECEMBER
1960 *Western Atomic Fair*, jointly sponsored by the American Nuclear Society and Atomic Industrial Forum, San Francisco. Details, Exhib Mgr., AIF, 3 East 54th Street, New York, 22

12–16 DECEMBER
*Use of Radioisotopes in the Study of Endemic and Tropical Diseases*, IAEA Symposium, Bangkok, Thailand

13 DECEMBER
*Analysis of waters used in industry*, Birmingham. Details, Society for Analytical Chemistry, 7–8 Idol Lane, EC3

14–16 DECEMBER
1960 Annual Conference of the Atomic Industrial Forum, San Francisco, California

15–16 DECEMBER
Autumn meeting, Powder Metallurgy Joint Group, includes symposium on *practical aspects of pressing metal powders*, Church House, Great Smith Street, London, SW1

**1961**

3–9 JANUARY
*48th session of Indian Science Congress*. Details, General Secretary, 64 Dilkhusa Street, Calcutta 17

10–12 JANUARY
*Physics of Polymers*, including Irradiation effects, conference, University of Bristol. Details, the Secretary, The Institute of Physics and The Physical Society, 47 Belgrave Square, SW1

## *Future Months*

20–26 FEBRUARY
International Congress on *semiconductor devices*, Paris. Details, Exhibition Services, 23 Rue de Lubeck, Paris 16e

28 FEBRUARY
*Safety of Nuclear Marine Propulsion Plant*, joint panel, J. M. Murray and H. Pemberton, organized by The Institute of Marine Engineers, 76 Mark Lane, London, EC3

15 MARCH
*Burst Slug Detection* Symposium, London. Details, The Society of Instrument Technology, 20 Queen Anne Street, London, W1

# Industrial Literature

**Particle accelerators.** The latest issue of Allis-Chalmers' 'Electrical Review' includes an article on US investigations into new concepts of accelerator design, using higher beam intensities.

★ 248

**Water treatment.** Following the recent agreement between Belco and Head Wrightson, the latter have now issued a booklet briefly describing processes offered in the field of water demineralization.

★ 249

**Control devices.** Recent specifications from Bailey Meters cover the 'Mini-line' level transmitter for non-corrosive fluids, an electronic transistorized resistance bridge for temperature control and alarm, and a remote adjustable computing relay for pressure-temperature compensation.

★ 250

**Heat treatment furnaces.** A recent brochure from Efco introduces a wide variety of equipment ranging from small laboratory furnaces to elaborate installations.

★ 251

**Nuclear engineering.** A brief introduction to the nuclear materials and products handled by the BSA Group, includes zirconium, boron and vacuum melted steels, 'Hylite' titanium alloys and machinery for beryllium, fuel element and uranium oxide handling.

★ 252

**Nuclear instruments.** Baird-Atomic's catalogue A-4 details the specifications for an extensive range of laboratory instruments and includes radiation counting systems, ratemeters, scalers, amplifiers, analysers, and detectors. Likely to be of use are the charts showing isotope medical applications, optimum counts, and scaler assemblies.

★ 253

**Commercial glass.** Corning's new edition of 'Properties of selected commercial glasses' contains information of several new glasses as well as new sections on thermal expansion and optical properties.

★ 254

**High temperature thermocouples.** The first issue of Engelhard's 'Technical Bulletin' contains an article on the development of high temperature thermocouples using noble metals. Their range of platinum/platinum-rhodium thermoelements are also featured in a separate leaflet.

★ 255

**Phase meter.** Design details of a new transistorized phase meter, type 630, are given in a recent issue of the Dawe Digest.

★ 256

**Refractory materials.** Carborundum's recent issue of 'Advanced Materials Technology' includes the properties and applications of new silicon carbides, boron nitride and carbide, fused magnesium oxide, zirconium and hafnium.

★ 257

**Lubrication dispersions.** A revised booklet from Acheson gives the properties and application of 38 graphite, molybdenum disulphide and resin-bonded dispersions. Another publication introduces the range of greases and compounds for other specific lubricating problems.

★ 258

**Electrical insulation.** Micanite's publication GB-8-60 details the properties of Paxolin glass laminates suitable for applications up to about 200°C, and of varnished glass fabrics for higher temperature applications.

★ 259

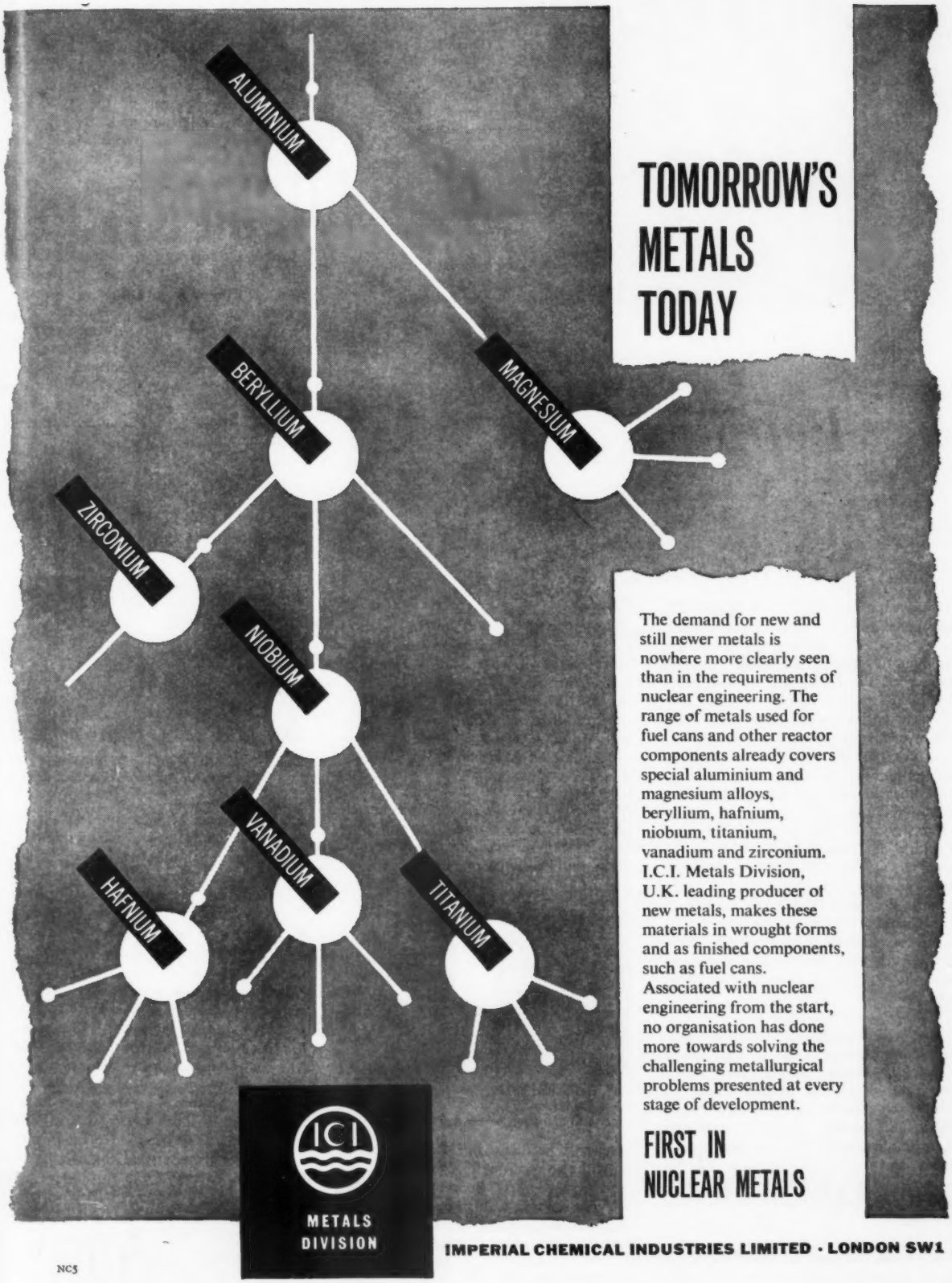
**Centrifugal fans.** Specifications for the 'Sirocco L.D. type forward curved multi-bladed fan with diameters ranging from 12⅞ in. to 49¼ in., are given in Davidson's publication 503/60.

★ 260

**Particle accelerators.** 'Radiation Review', a new newsletter series from Radiation Dynamics, directed to users of radiation in research, commences with a discussion on high current accelerators for low yield experiments.

★ 261

★ *For further information on any item, circle the appropriate number on the reply card facing page 150.*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**DRESDEN CEREMONY** Mr Ralph Cordiner (left), chairman of the US General Electric Board, fastens the last bolt to fit the control key to the master control console of the Dresden nuclear power station at its formal dedication recently. With him (centre) are Mr J. A. McCone, chairman of the AEC, and Willis Gale, chairman of the board of Commonwealth Edison Co., the operators of the station

# *People*

*by John Radford*

THIS year's Nobel Prizes in physics and chemistry have gone to two American professors. For his invention of the bubble chamber, **Professor Donald Glaser** of the University of California has been awarded the physics prize. The chemistry prize goes to **Professor Willard Libby,** a former member of the USAEC, for inventing the carbon-14 method of determining age in archaeology, geology and other branches of science. Professor Libby was for nine years professor of chemistry at the University of Chicago's Institute of Nuclear Studies and was a member of the USAEC from 1954–59. Last year he won the Albert Einstein award. Professor Glaser has worked at the University of Michigan and joined the research group at Berkeley, California, this year. He designed and operated the first bubble chamber eight years ago.

Three visitors from the Finnish State Board were recent guests of the Central Electricity Board. During their week's stay, the delegation—**Raimo Tuuli,** an expert on nuclear engineering; **Tauno Rask,** a thermo specialist and **Mr Laurila,** director of the electrical department and a director of the Finnish agency—visited Bradwell, Calder Hall and High Marnham (near Retford) power stations.

The export company of Associated Electrical Industries Ltd is to have a single managing director instead of three joint managing directors. He is **Mr F. R. Mason. Mr E. V. Small,** one of the three joint managing directors, has retired from executive work and is appointed consultant; **Mr H. West,** managing director of AEI (Manchester) Ltd, also becomes a director of the export company and **Mr B. A. Hensler,** one of the previous joint managing directors, will continue as a director.

**Mr W. G. Harrison,** new general manager of Dynatron Radio Ltd, will now have overall responsibility for co-ordinating the development, production and sales of the company's domestic and

W. G. HARRISON Dynatron general manager

G. A. SMITH to co-ordinate Plessey sales

electronic products. For the time being, he will also continue to control the commercial aspects of domestic radio and television. Prior to his appointment, Mr Harrison was sales manager of the radio and television sales division.

Co-ordinating the four sales organizations within the Plessey Group is the task facing **Mr George A. Smith** whose appointment as Commercial Executive of the Group was announced by **Mr Michael Clark,** Director of the Electronic and Equipment Group of The Plessey Company Ltd. Until recently, Mr Smith was general manager of the Telecommunications Division and before that was responsible for overseas sales of electronic equipment for Plessey International Ltd.

Italian-born **Pier F. Talenti** has been appointed vice-president of Fairbanks-Morse & Co's newly formed International Division and **Frank Gervasi,** vice-president for European operations, with headquarters in Rome. An engineer and banker, Mr Talenti was formerly vice-president in charge of the international banking department of the First Western Bank of San Francisco while Mr Gervasi, a noted engineer and journalist, was formerly Chief of Information for the Marshall Plan in Italy.

Recent developments at Foster Wheeler Limited include the election of **Mr C. E. H. Verity,** the managing director, as a director of their parent company,

C. E. H. VERITY US directorship

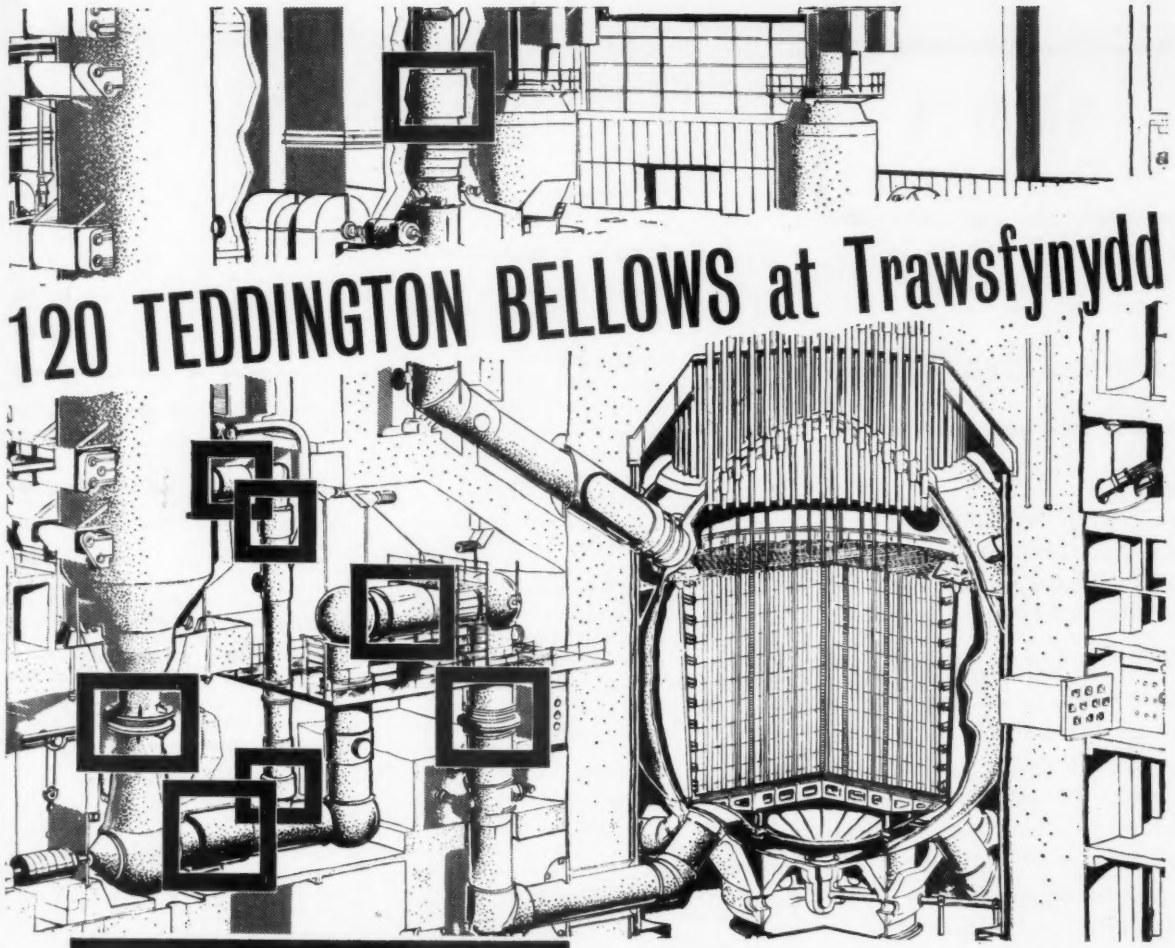
A. P. TABER controls US B & W research

Foster Wheeler Corporation of New York. This company and its subsidiaries are international builders of processing plants and steam power equipment. Also disclosed was the appointment to the company's board of Messrs **R. L. J. Haydon, C. J. Geiss, J. F. G. Arman, A. S. Bridgwater,** and **J. McLean.**

Now in charge of the research and development division of the US Babcock & Wilcox is **Mr Alden P. Taber,** who has been elected a vice president. He will control the company's research and development work and also be responsible for co-ordinating this work among the company's subsidiaries. Before joining Babcock & Wilcox, Mr. Taber was professor of metallurgical engineering at Syracuse University.

**Dr H. J. Bhabha,** chairman of the Indian Atomic Energy Commission, is again in the news—he has been elected President of the International Union of Pure and Applied Physics.

# 120 TEDDINGTON BELLOWS at Trawsfynydd



*By courtesy of 'NUCLEAR POWER'*

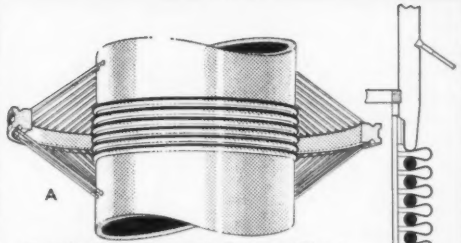


*Illustration A represents one of the Teddington Stainless Steel Bellows supplied to Trawsfynydd with a novel form of restraint designed by Richardsons, Westgarth & Co. Ltd. (a member of Atomic Power Constructions Ltd.). This avoids the use of highly stressed hinge pins and permits a complete gimbal movement.*

*Illustration B indicates a section of Teddington Bellows, showing the restraining rings for extra strength which are a feature of this bellows design.*

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General Editor: J. C. COLLINS, B.SC., M.S.E., A.M.I.C.E., Department of Municipal Engineering, Faculty of Technology, University of Manchester.

The first half of the book is of a fundamental nature, explaining the problems which have to be understood when dealing with radioactive material. The second half deals specifically with the treatment and disposal of liquid, solid and gaseous radioactive wastes, and includes valuable information on the results of laboratory work, and on the experience gained in operating treatment plants in different parts of the world. Each chapter has been contributed by an expert.

★

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SIR ALEXANDER FLECK, K.B.E., D.SC., F.R.S. (in his foreword to the book)

★ 262

# Book Reviews

## Spectroscopist's handbook

**Applied Gamma-Ray Spectroscopy** edited by C. E. Crouthamel, Pergamon, London, 1960: Price 50s

This is primarily a reference book for the radiochemist, and its main emphasis is on the applications of gamma-ray spectrometry to qualitative and quantitative analysis: it can, however, be recommended to any gamma-ray spectroscopist since it brings together much material that has heretofore been scattered among a number of sources. It contains well written accounts of many of the important practical problems in the field, ranging from the accurate calibration of detectors to methods of selecting photomultipliers and of handling and canning NaI crystals. Theoretical discussions are brief and consist mainly of quoting results that are important for practical applications.

The most striking feature of the book is the group of appendices which account for well over half the pages. It contains a number of useful tables, including one in which the radionuclides are listed successively by gamma-ray energy, atomic number and half life. There is also a 150-page 'atlas' of NaI scintillation-counter spectra for most of the radioisotopes, all taken in a standard geometry with 4″ × 4″ crystal. This 'atlas,' though interesting qualitatively, is of somewhat limited practical value since the details of experimental spectra depend so much on geometry and the size of crystal used. It is perhaps a pity that this compilation could not have been condensed and more space devoted to some of the many research applications of gamma-ray spectrometry that are completely neglected.

The book is well produced, and the editor is to be congratulated on maintaining throughout a uniformly high standard of style and quality.

**J. H. Montague**

## New Books

• *Computer engineering* edited by S. A. Lebedev (Translated from the Russian) Pergamon Press, London 1960 184 pp Price 63s

★ 263

• *Heat transfer engineering* by H. Schenck Longmans, London 1960 314 pp Price 28s

★ 264

• *Cathode ray tube memory of the high speed electronic computer of the USSR Academy of Science* by V. N. Laut and L. A. Lyubovich Pergamon Press, London 1960 90 pp Price 35s

★ 265

• *Instrumentation in scientific research: electrical input transducers* by K. S. Lion McGraw-Hill, New York and London, 1959 324 pp Price 74s

★ 266

• *Progress in metallurgical technology* Refresher lectures at the Institution of Metallurgists Iliffe, London 1960 147 pp Price 32s 6d

★ 267

• *Plasma physics and the problem of controlled thermonuclear reactions, Vol 2* (Translated from the Russian) Pergamon Press, London 1960 457 pp Price £8

★ 268

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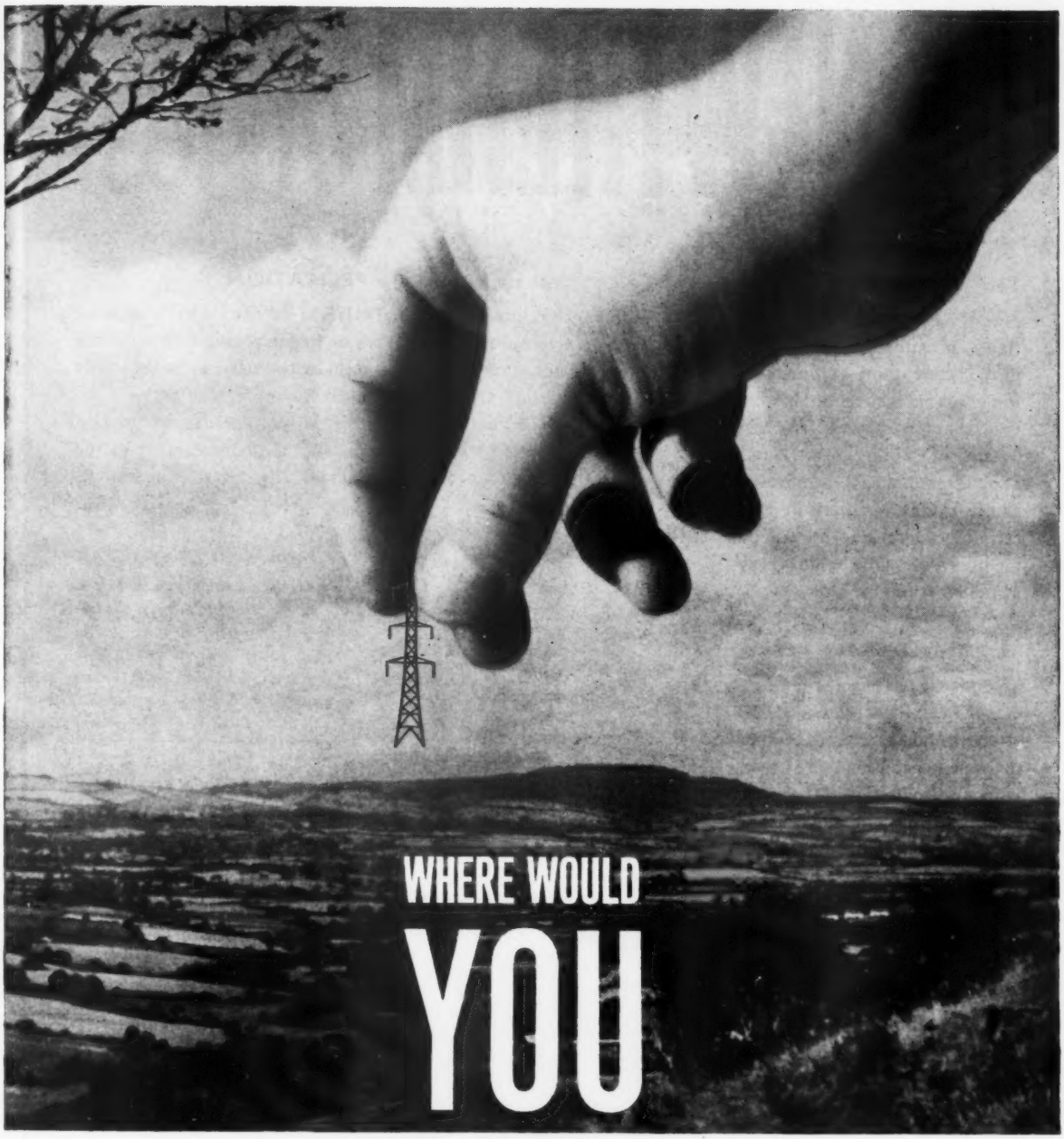


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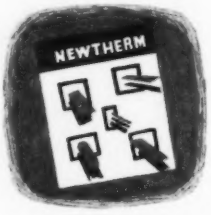


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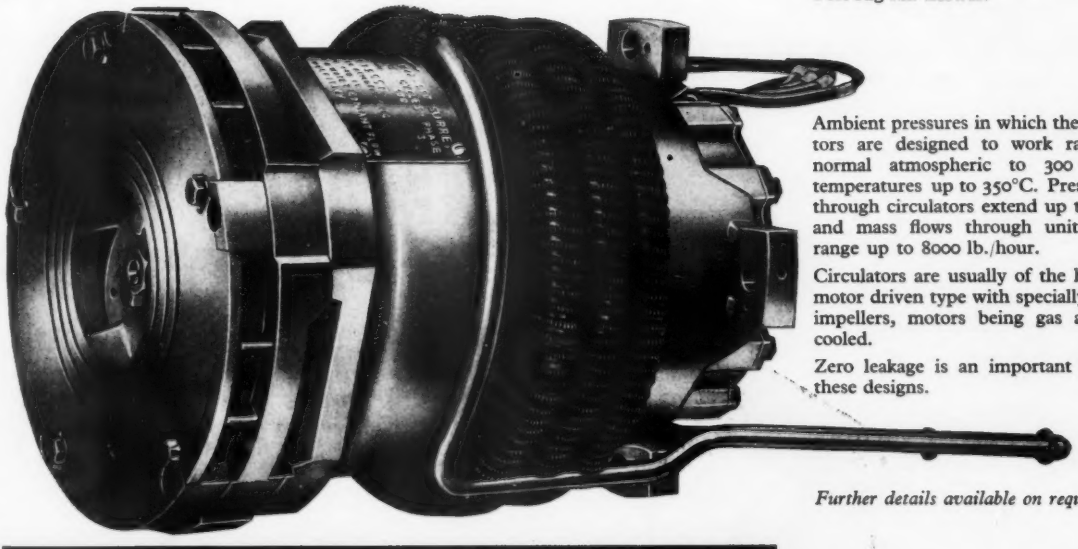

Ambient pressures in which these circulators are designed to work range from normal atmospheric to 300 p.s.i. at temperatures up to 350°C. Pressure rises through circulators extend up to 30 p.s.i. and mass flows through units cover a range up to 8000 lb./hour.

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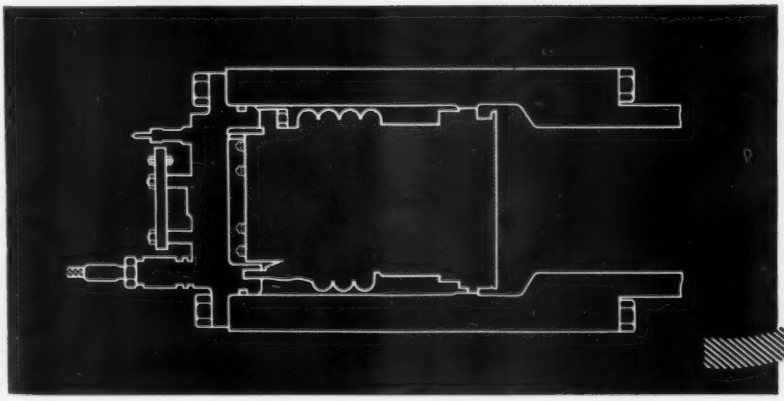
Zero leakage is an important feature of these designs.

*Further details available on request.*



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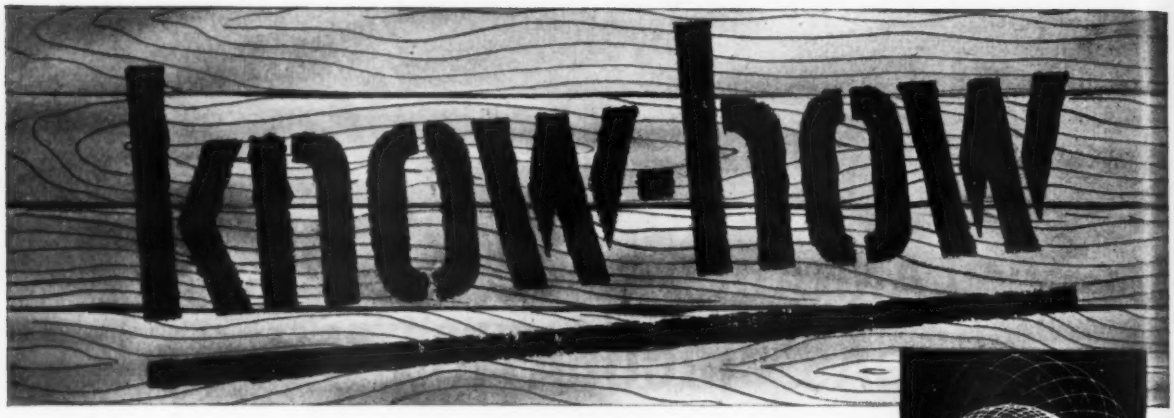


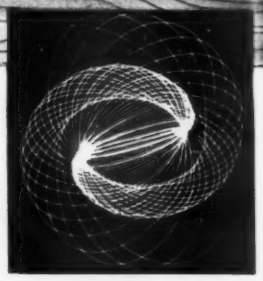

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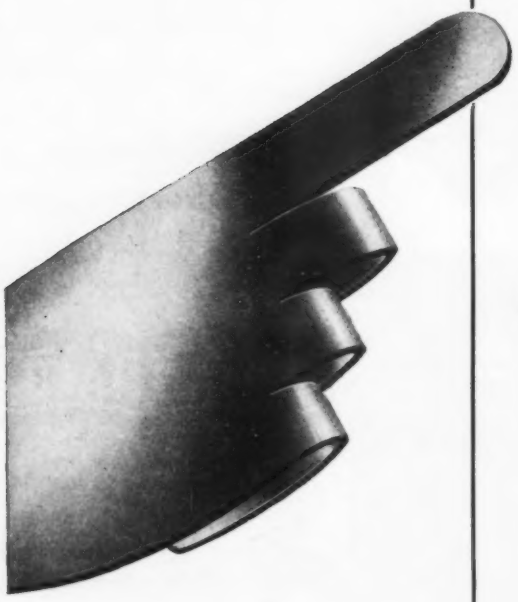

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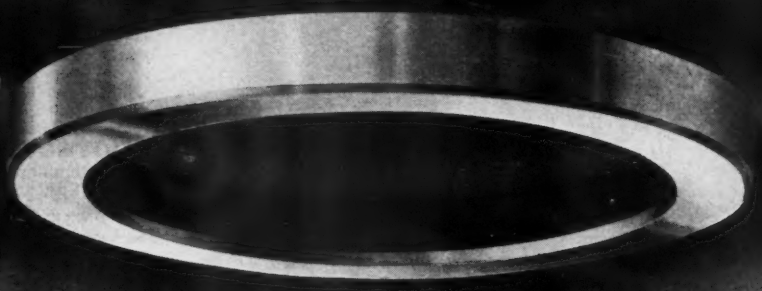

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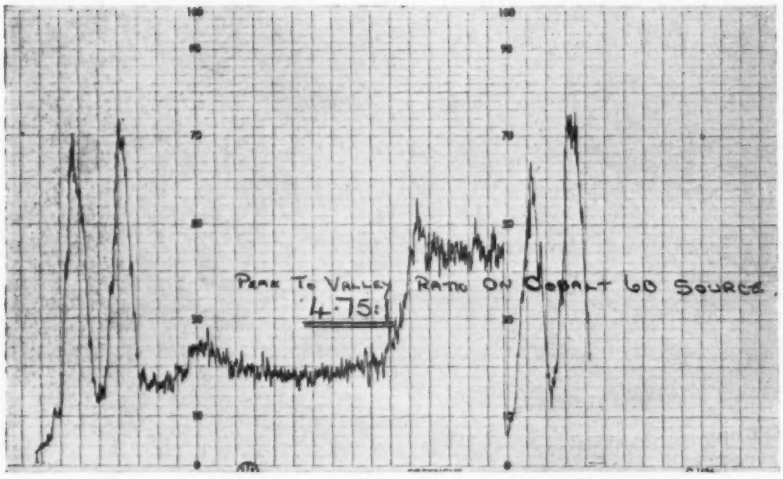



**The thallium-activated sodium iodide crystal is mounted direct on a photomultiplier.**

**HIGH RESOLUTION**
Peak-to-valley ratio of 4:1 with a Cobalt-60 source.

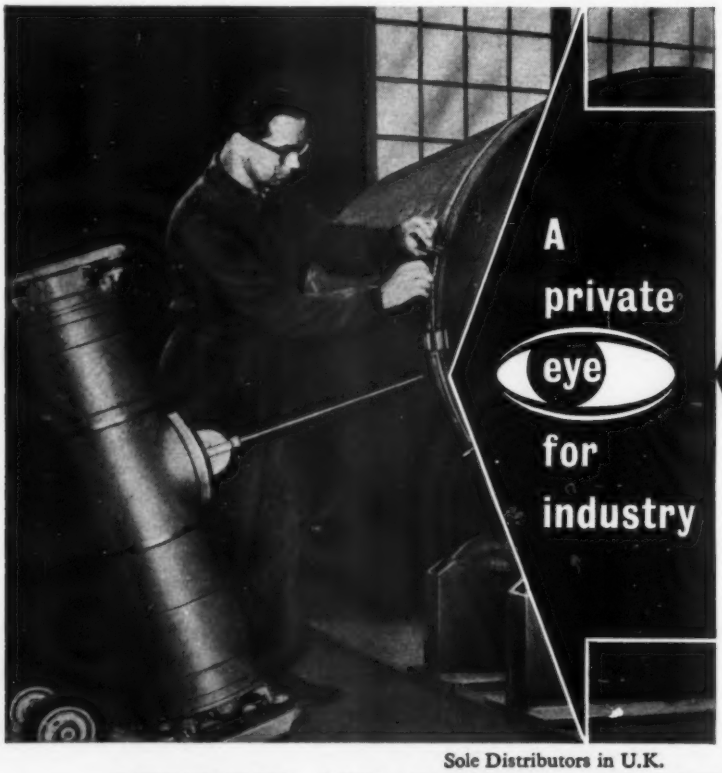
**LOW BACKGROUND**
Background radiation is due entirely to Potassium-40, and does not exceed 8 counts per second.

**PHOTOMULTIPLIER PROTECTION**
The photomultiplier is never exposed to direct light, and so its efficiency is preserved.

*3-inch assemblies and 1-inch counting probes. Catalogue CJ 39/c55 for details.*

HILGER & WATTS

**HILGER & WATTS LIMITED** 98 ST PANCRAS WAY · LONDON NW1 · *Tel GULliver 5636*




Ruggedly built, but still mobile, the Muller Macrotank H is specially developed for on-site radiographic examination in heavy industry, ship and bridge building, nuclear power and refinery construction — wherever complete and accurate weld examination is essential. The small focus (2.3 mm.) of the Macrotank H gives really sharp definition, with a penetration of up to 2¼" of steel with Pb screens in reasonable exposure time. It is low in cost, reliable in use, and backed by full service facilities which may be on contract if desired. We shall be glad to send you full details.

*The Macrotank H is a product of C. H. F. Muller, Hamburg.*

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Instrument House, 207, King's Cross Road, London, W.C.1. TERminus 2877

(RCL.0416A)

# GLASS DISTILLATION

## Units by

# Q·V·F

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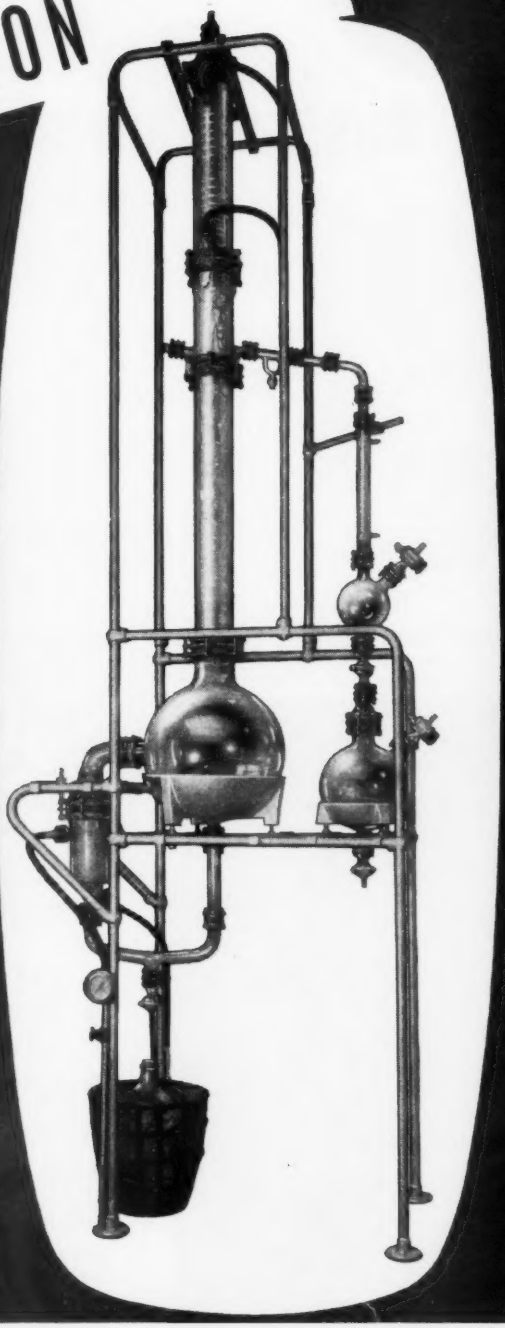
QUICKFIT *Visible Flow*



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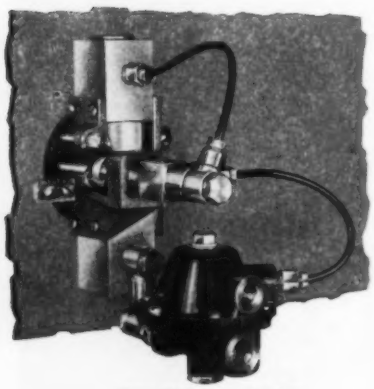
Front view. Common to all models.

These flow indicators (Type 715 series) are versatile units, simple to install and occupying the minimum of panel space, with no awkward front of panel projections.

# New flush mounting purge meters



Type 715D Back view.

**—packaged units with pressure regulators**

- One hole fixing
- No projections in front of panel
- Needle valve operation by coin slot
- Coin slot discourages unauthorised adjustment
- Self contained units reduce installation costs
- Can be spaced as close as 4″ centres

*The series consists of four instruments*

Type 715 A . . . . Simple indicator
715 B . . . . Indicator with needle valve
715 C . . . . Indicator, needle valve, and simple pressure regulator
715 D . . . . Indicator, needle valve, and differential pressure regulator

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FLUID MEASUREMENT AND CONTROL
FLOW-DENSITY-LEVEL

Leaflet N.P. 2021/34 is free on request

**ROTAMETER MANUFACTURING CO. LTD. · 330 PURLEY WAY · CROYDON · SURREY · Tel: CRO 3816 · Telex: 24292**
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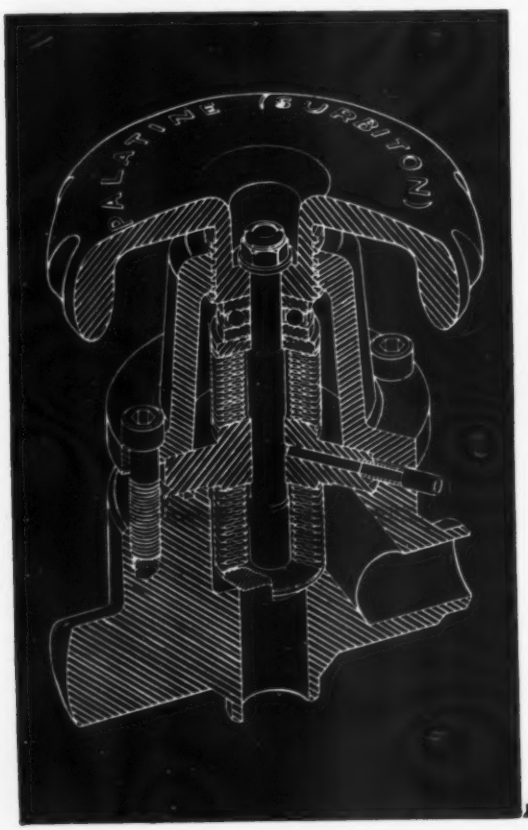


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- HARD FACED POPPET OR DISC INSERTS

*Palatine design and supply a wide variety of Valves to U.K.A.E.A. at Capenhurst, Aldermaston, Harwell, etc. and to the Chemical and Petroleum Industries.*

**REMOTE CONTROL VALVES OPERATED BY AIR DIAPHRAGM OR PNEUMATIC MOTORS—ELECTRIC ACTUATORS—VERY COMPACT HIGH TEMPERATURE —VACUUM—LIQUID VALVES. PORTING AND STUBS TO CUSTOMER'S REQUIREMENTS.**

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*MEL have also developed techniques for the separation of zirconium and hafnium and for the production of vanadium and can supply:*
*Zirconium compounds with a hafnium content down to 100 p.p.m.*
*Hafnium compounds with a zirconium content of 2%*
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Magnesium Elektron, Inc., New York 20, USA


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Illustrated is the twin cylinder model having a free air delivery of 50 c.f.m.

# W&J OIL FREE COMPRESSORS

**DISPLACEMENT RANGE 1 to 136 c.f.m.**

In the Food Processing, Brewing, Chemical and Paper Industries, also for pneumatic instrument control, it is essential that the air is free from oil in both droplet or vapour form. The W&J compressors use carbon rings and completely dry cylinders to achieve this purpose.

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*For further details please write requesting Leaflet Nos. 4, 20, and 28.*

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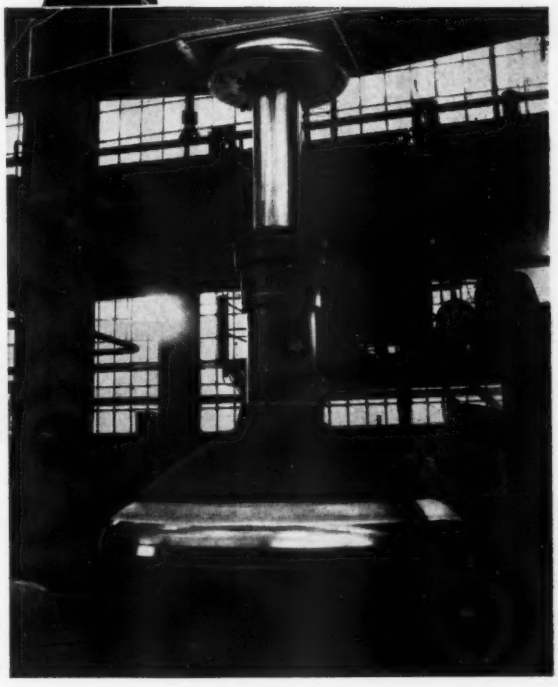
# Over a Ton of Aluminium Alloy spun to 10 ft. i/d x $1\frac{5}{8}$"

One of a number produced for pressure vessels to hold liquid air, this 10 ft. aluminium end was spun by Harveys on the Rotarpress. The 12 ft. flat discs needed for spinning these ends, which are believed to be the largest spun aluminium ends produced in this country, were formed by butt-welding two plates of aluminium alloy together.



The Rotarpress is one of the large-capacity units in Harveys Heavy Fabrication Department. It produces ends up to 15 ft. diameter and is adaptable over a wide range of knuckle radii and depths.

The contours of semi-ellipsoidal ends produced by the spinning process enable plate thickness to be reduced, and in most cases tool costs are eliminated. Enquiries are invited for ends only or for complete

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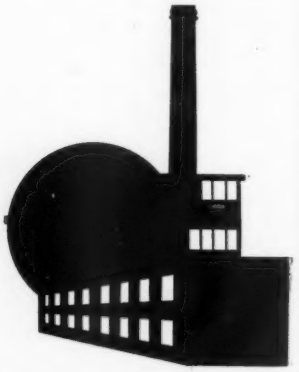

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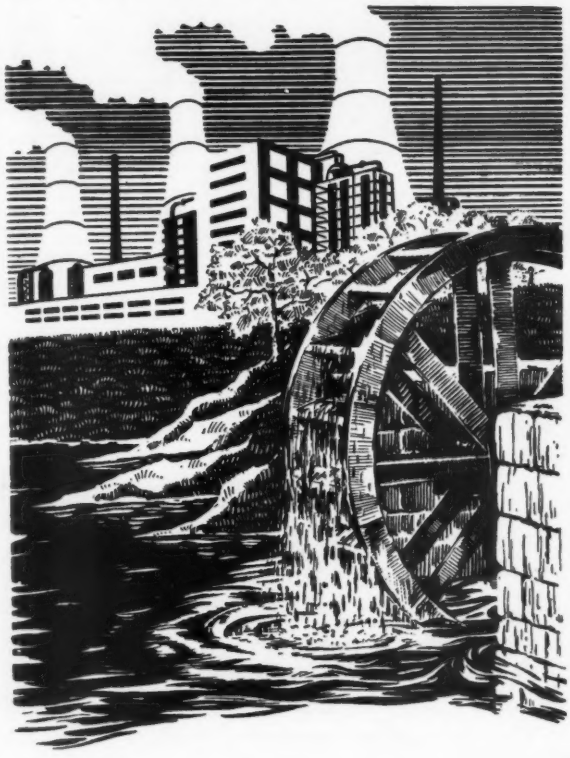

*WATER*

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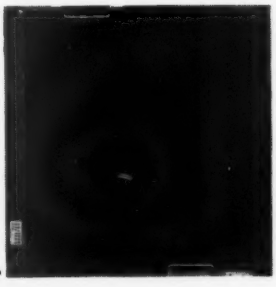

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# ASTRONOMICAL ACCURACY

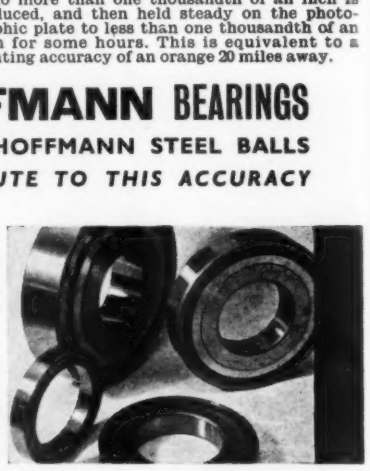
*By courtesy of the Mount Wilson and Palomar observatories*

## NEW 74 INCH REFLECTING TELESCOPE

This large Telescope manufactured by the Sir Howard Grubb Parsons Company, is for the Okayama Astrophysical Observatory which is a branch of the Japanese Tokyo Astronomical Observatory, and will be one of the largest ever to be erected in Asia.
The main optical component, a parabolic glass mirror, collects light from distant stars and focuses it either on to a photographic plate or on to a slit of the spectroscope. The mirror weighs about 11 tons and is 74 inches in diameter.
Fifty tons of complex mechanisms can be put into motion by push button control and direct the Telescope with such precision that a star image of no more than one thousandth of an inch is produced, and then held steady on the photographic plate to less than one thousandth of an inch for some hours. This is equivalent to a pointing accuracy of an orange 20 miles away.

## 176 HOFFMANN BEARINGS AND 300 HOFFMANN STEEL BALLS *CONTRIBUTE TO THIS ACCURACY*

The Hoffmann Manufacturing Company have supplied the main Polar Axis bearings and many smaller bearings on other moving parts of the Telescope. The diversity of these applications amply justifies our claim for the suitability, efficiency and dependability of Hoffmann bearings.



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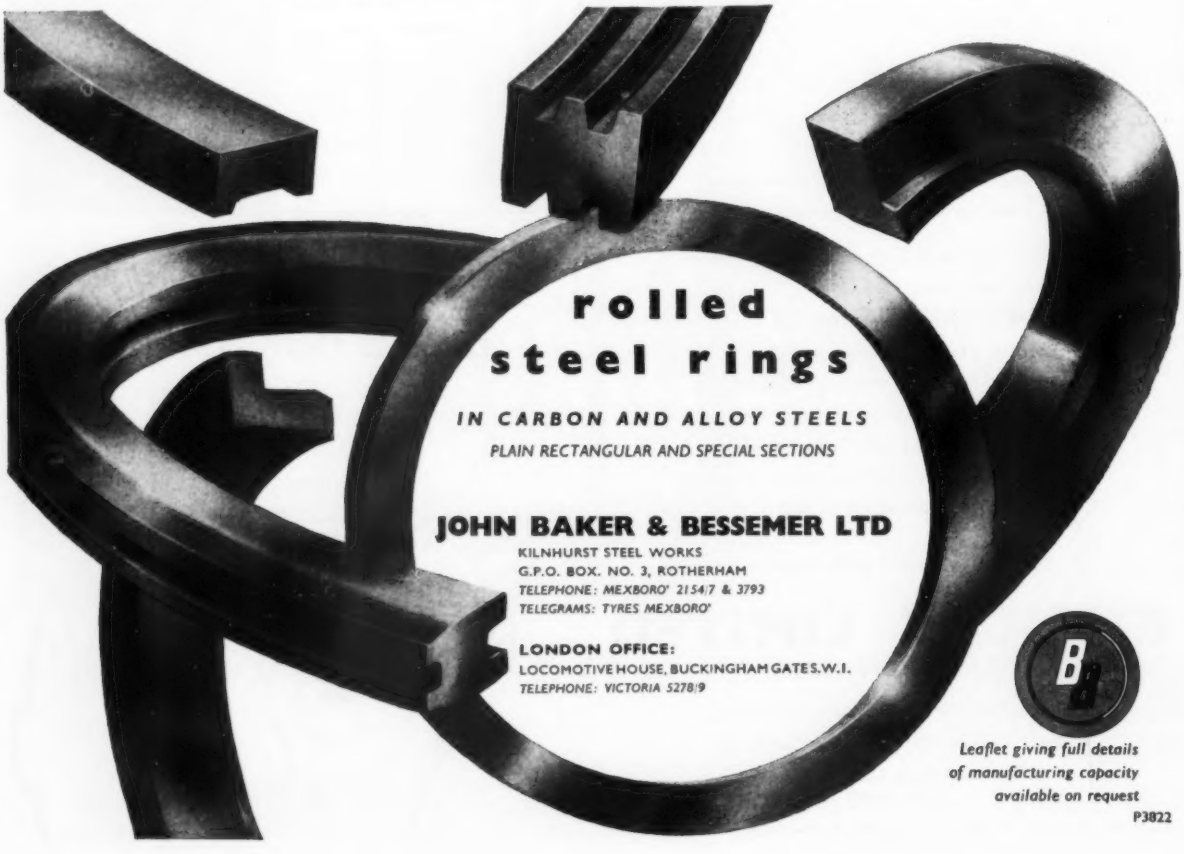

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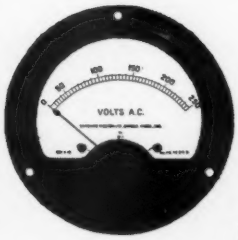

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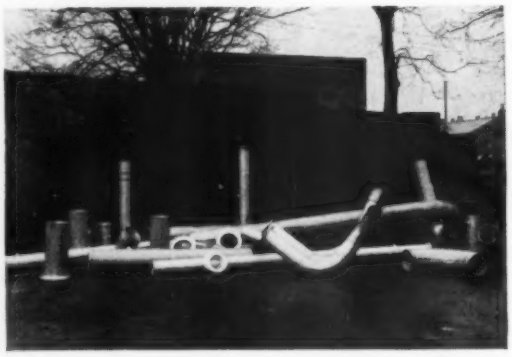

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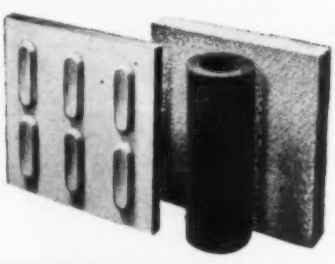

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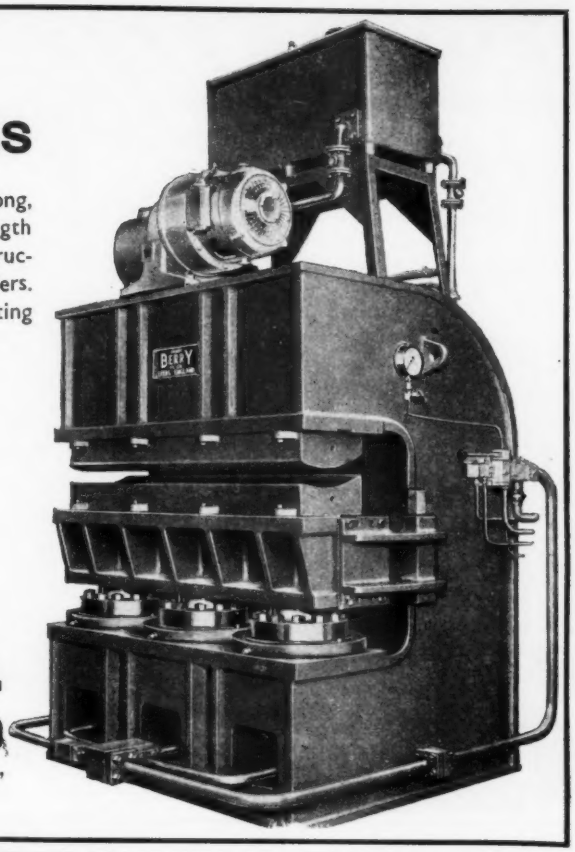


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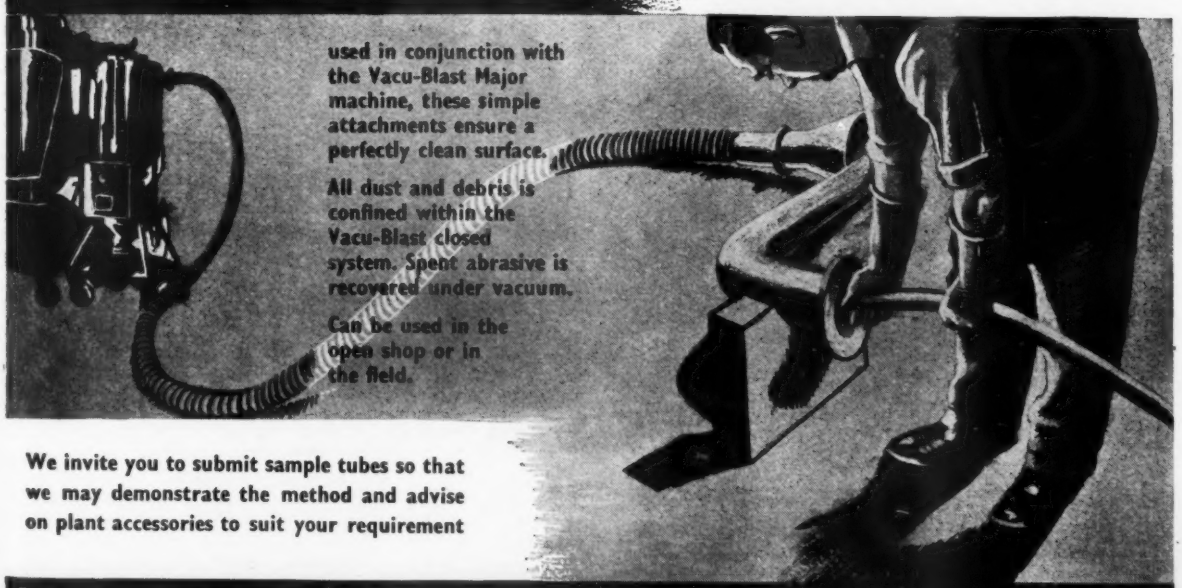

**used in conjunction with the Vacu-Blast Major machine, these simple attachments ensure a perfectly clean surface.**

**All dust and debris is confined within the Vacu-Blast closed system. Spent abrasive is recovered under vacuum.**

**Can be used in the open shop or in the field.**

**We invite you to submit sample tubes so that we may demonstrate the method and advise on plant accessories to suit your requirement**

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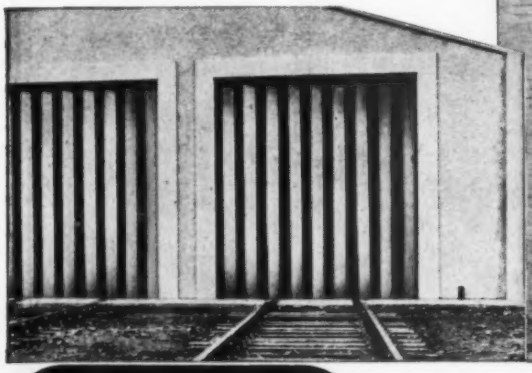

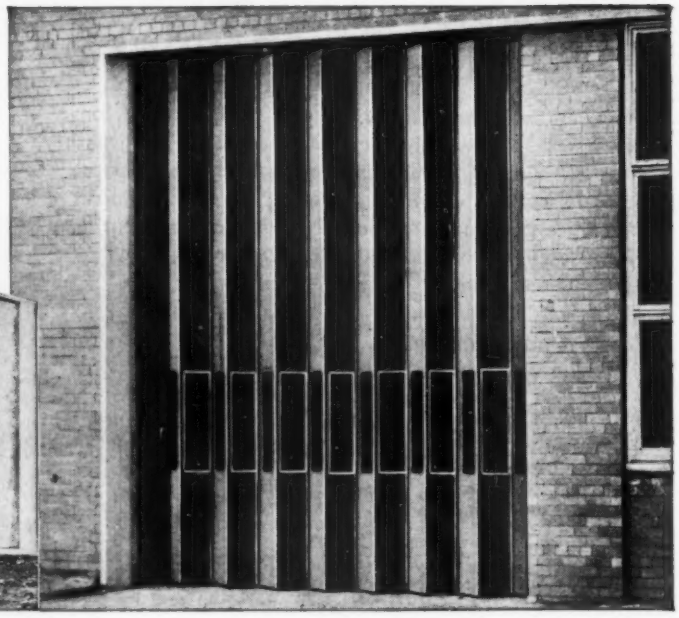

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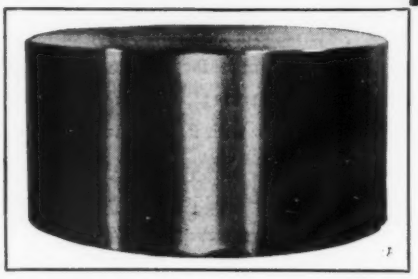
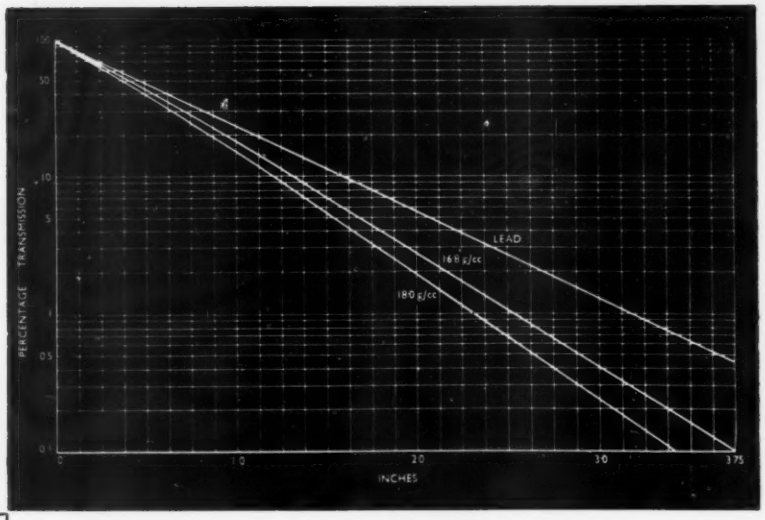


*The above piece of G.E.C. Heavy Alloy was made for the United Kingdom Atomic Energy Authority. It weighs 660 lb.*




Broad beam absorption of Gamma-radiation from COBALT-60. Density: 16·8 g/cc. and 18·0 g/cc.

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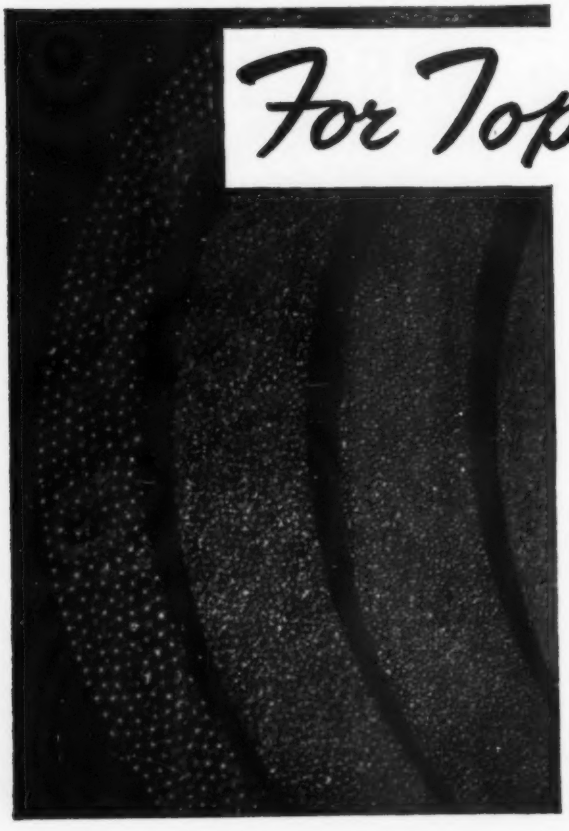

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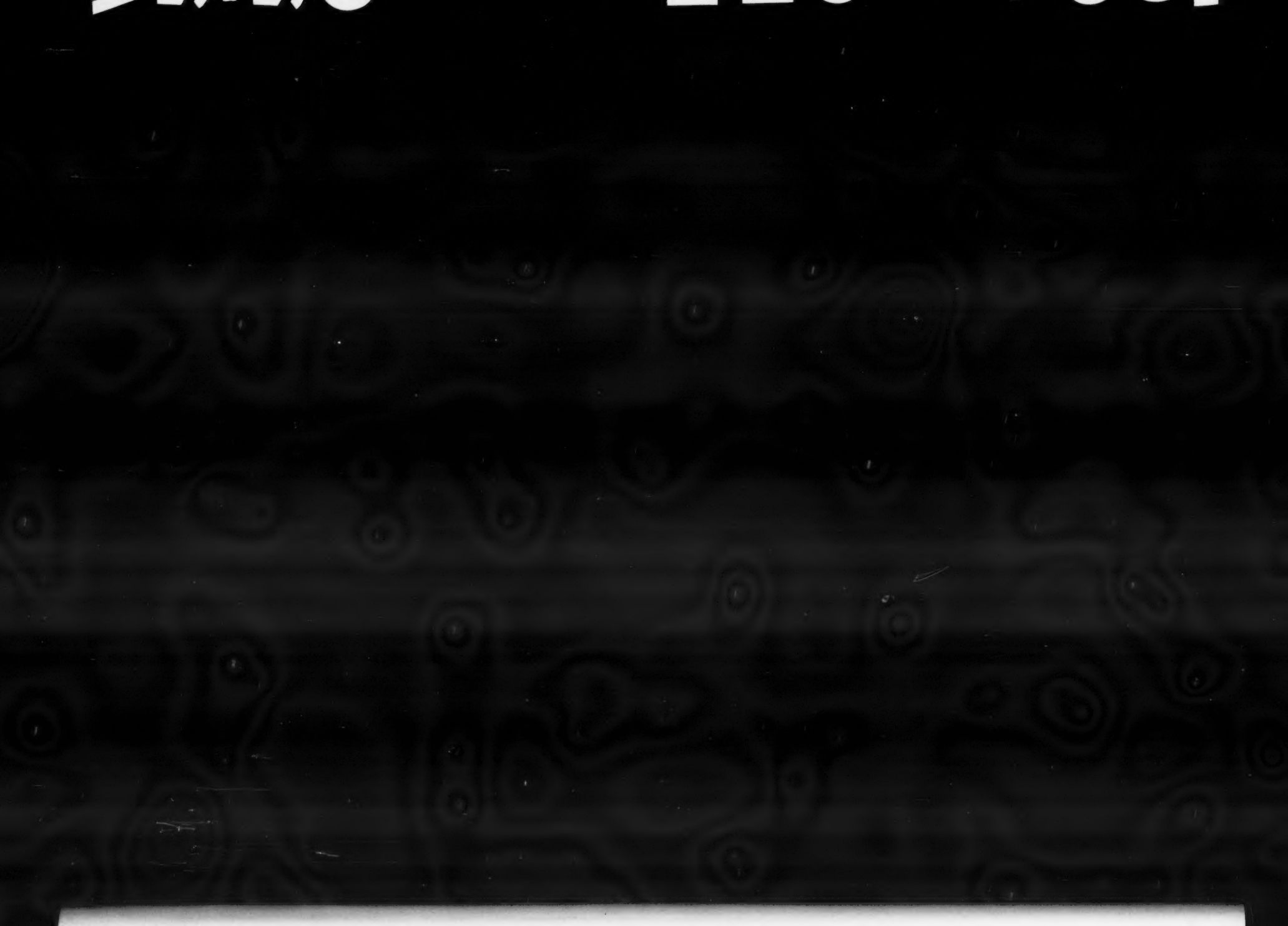

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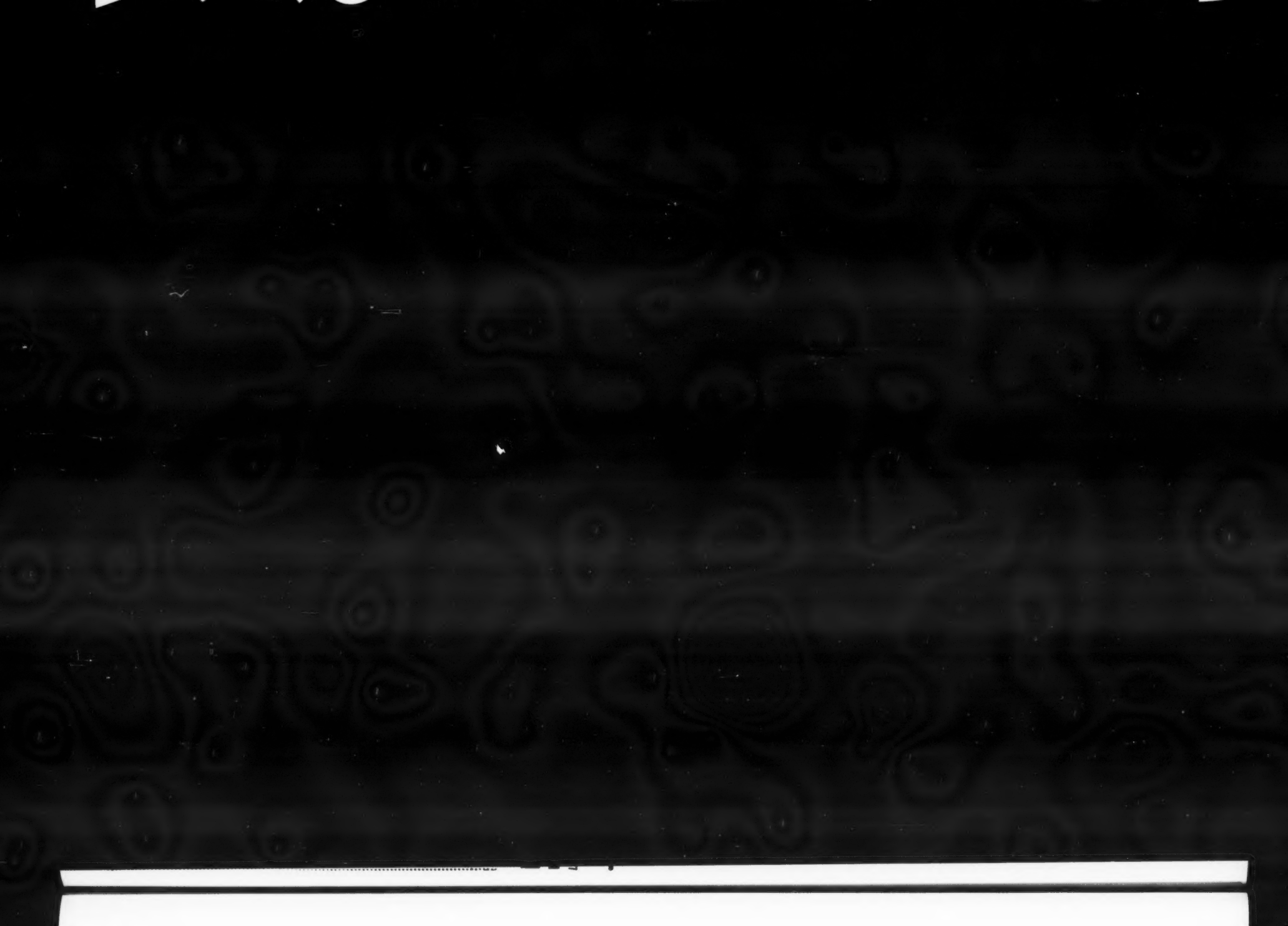

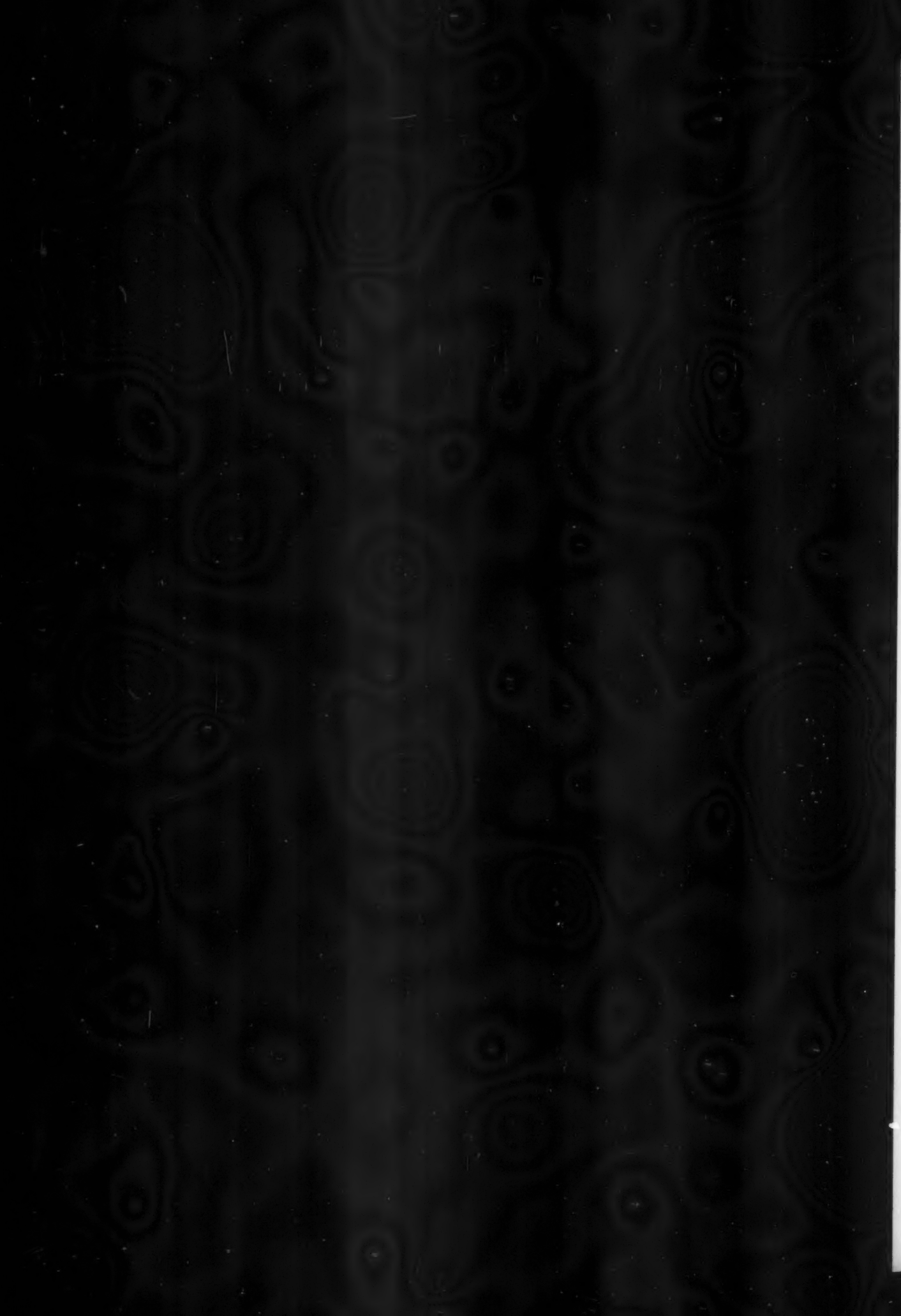

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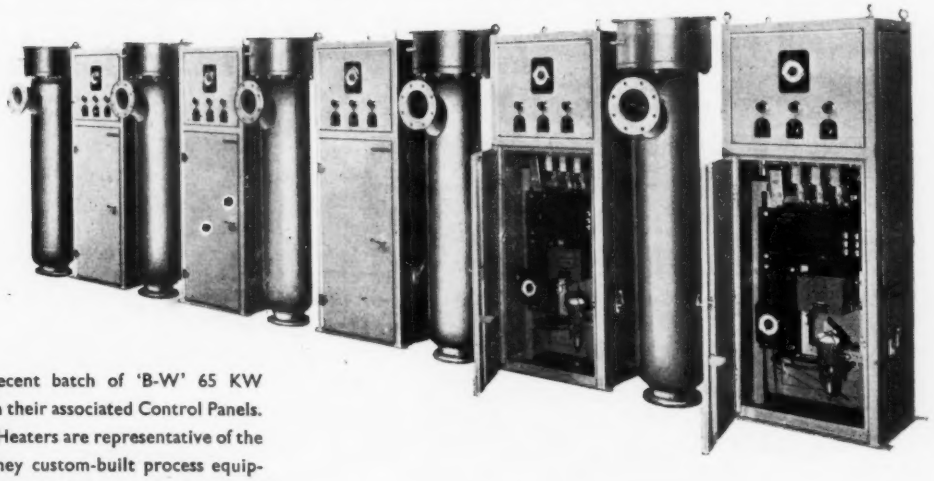

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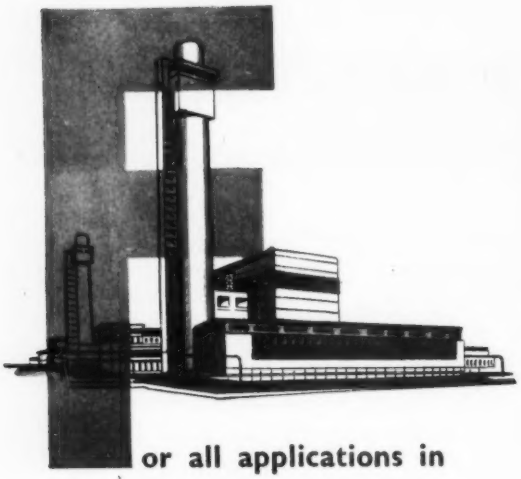

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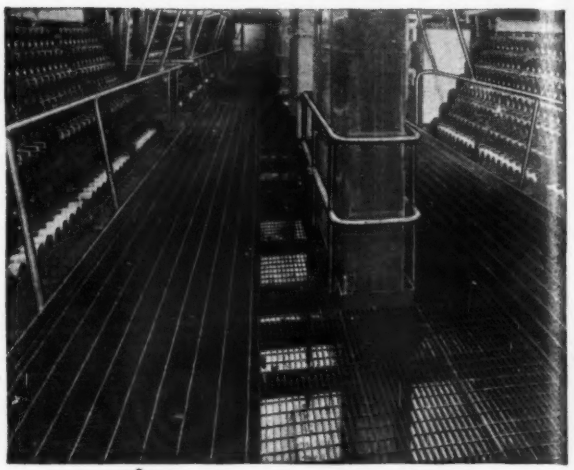

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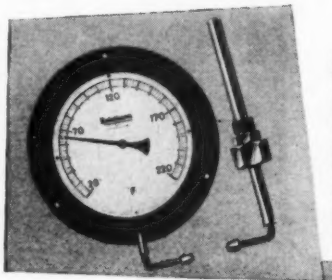

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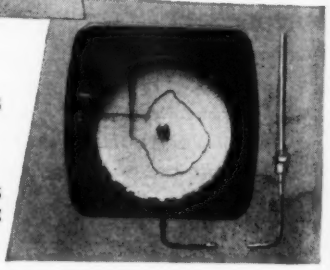

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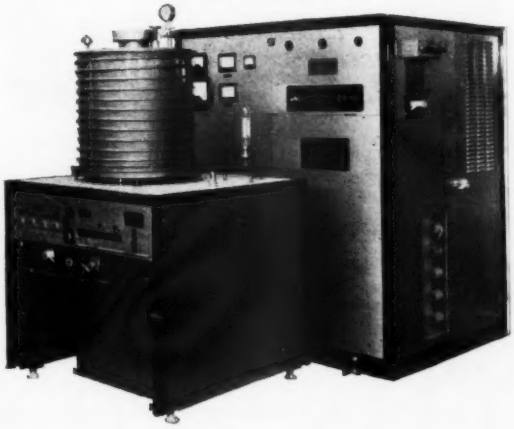

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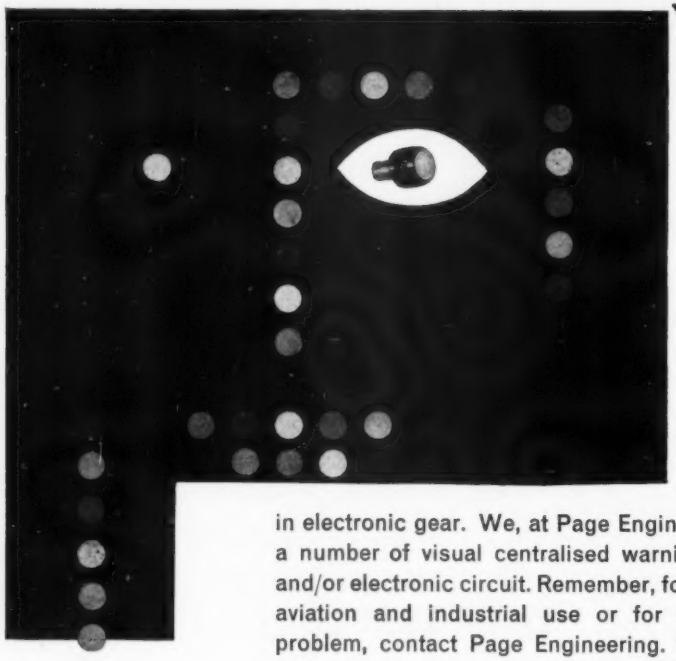

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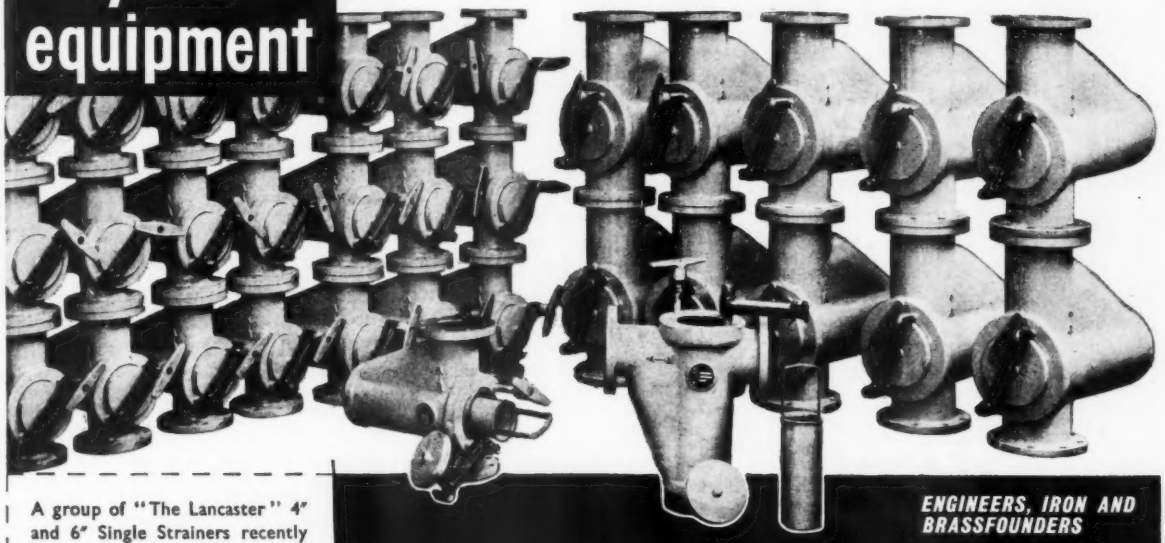

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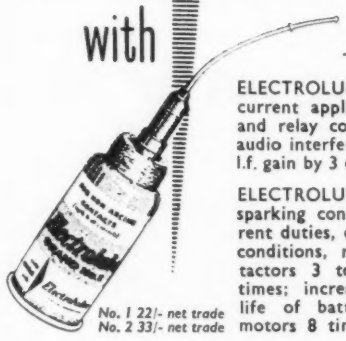

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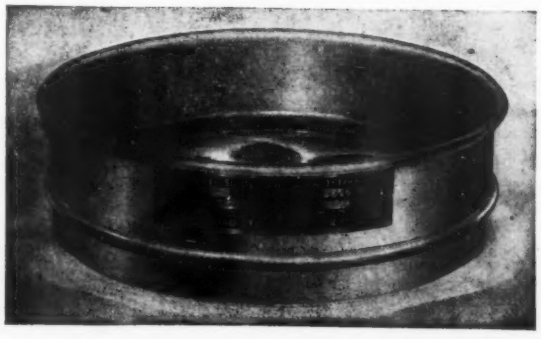

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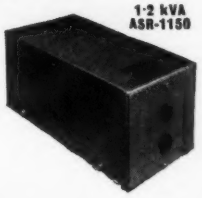

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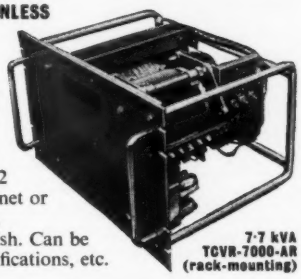

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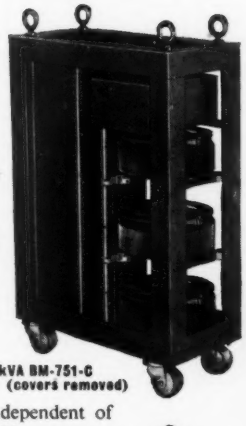

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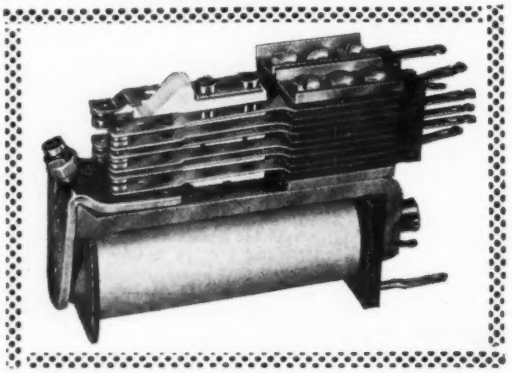

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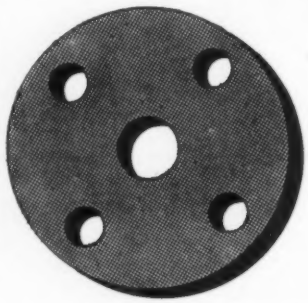

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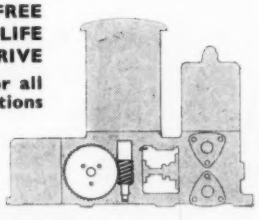

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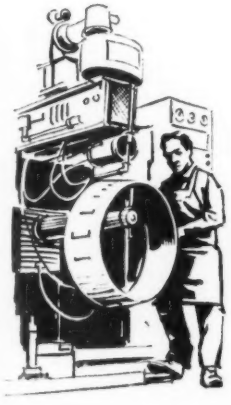

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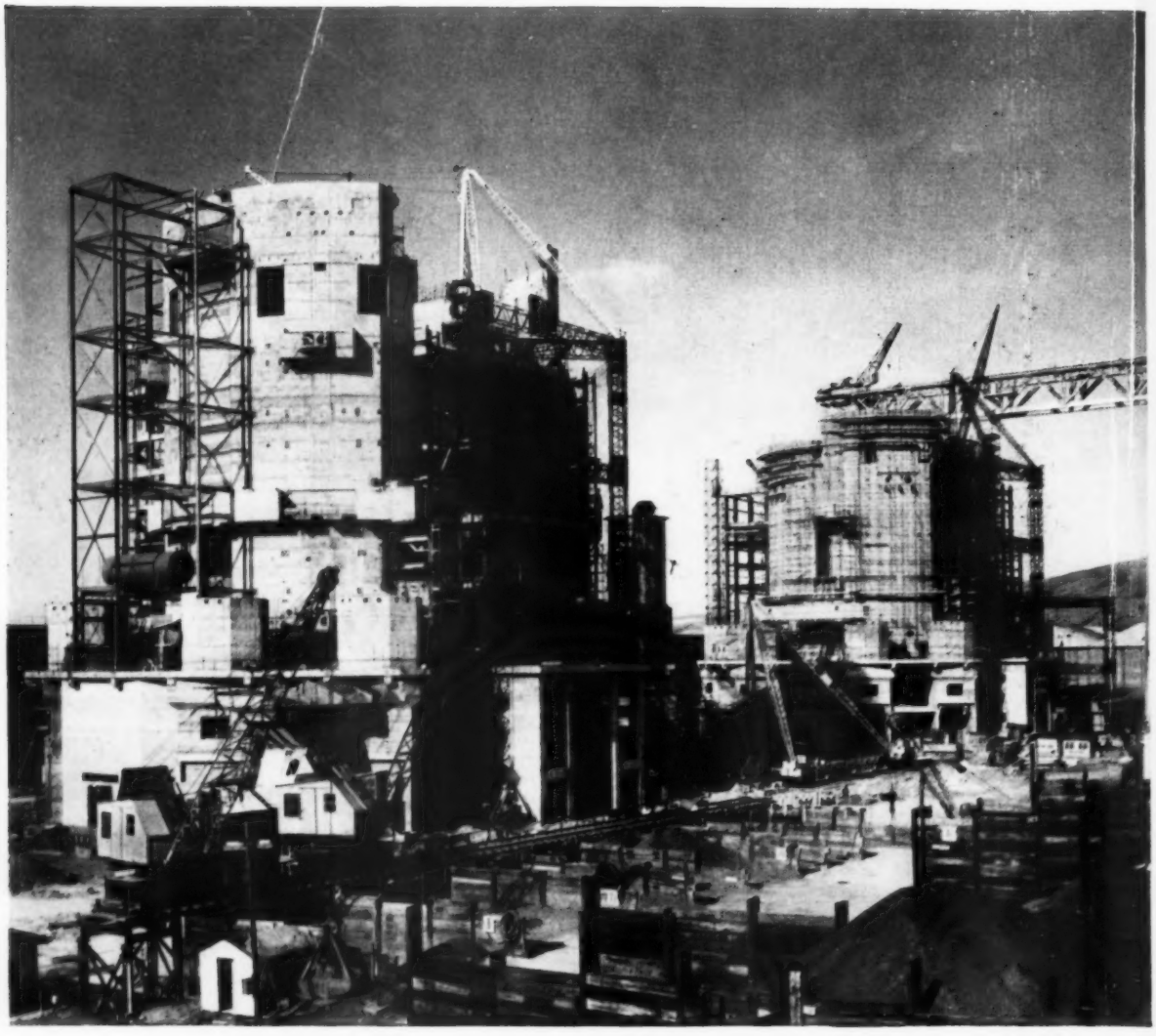

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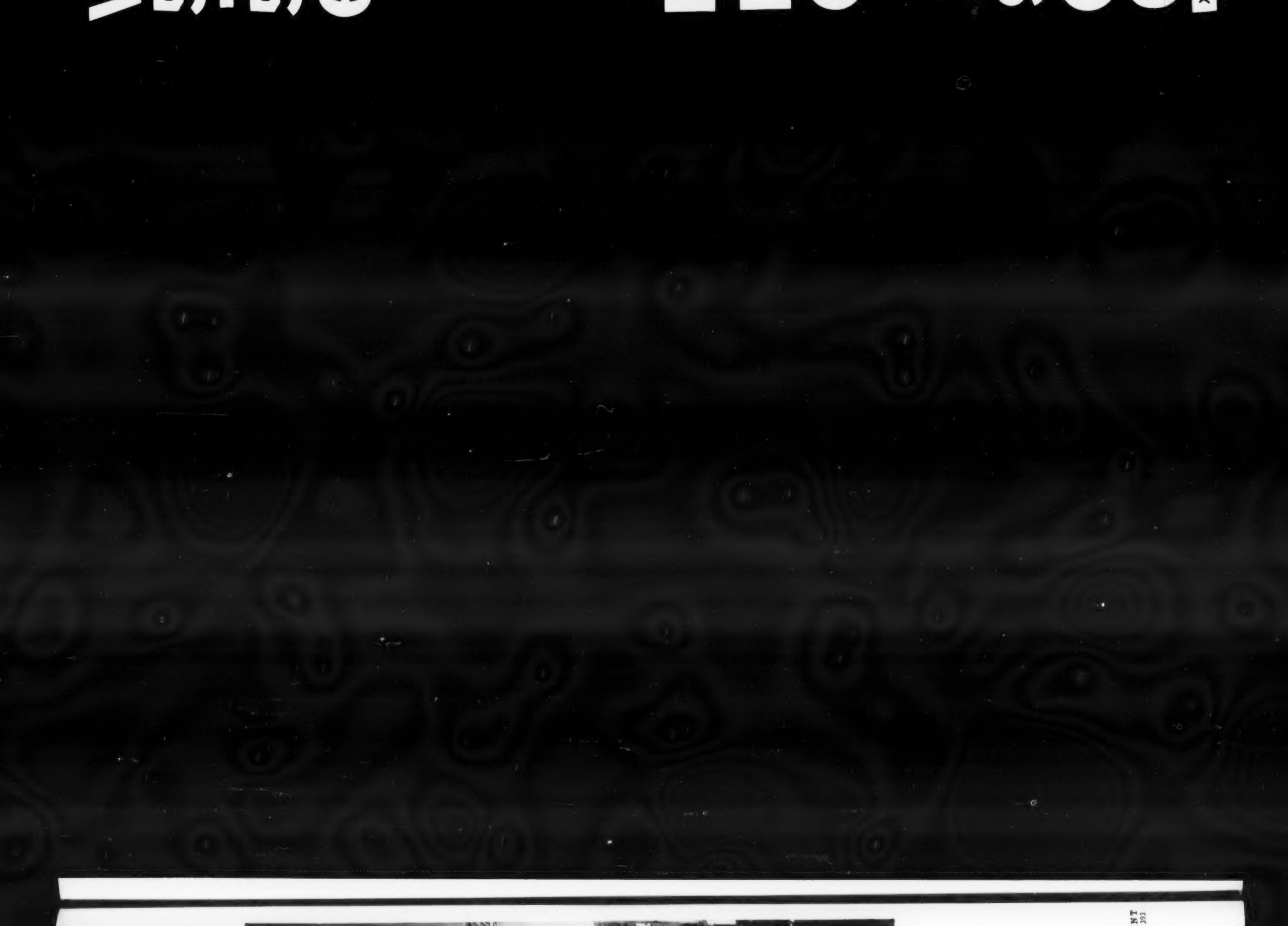
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